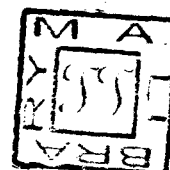


**A STUDY
OF
DIRECTIONAL ASSYMMETRY
WITH
NUCLEAR EMULSION PLATES.**

1955



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M.Sc.

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CHECKED 1996-97

THIS IS
submitted for the degree
of
Doctor of Philosophy
of
MUSLIM UNIVERSITY, ALIGARH.

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STUDY OF
Directional asymmetries
With
Photographic Emulsion Technique

The work given in this thesis has been carried out in the Physics Laboratories of Muslim University, Aligarh, under the guidance of Prof. P. S. Gill, M.S. (S. California), Ph. D. (Chicago), F.N.I. to whom the author is highly indebted for valuable suggestions and useful discussions at all stages of the work.

The author is also very thankful for the help of his colleagues and specially that of Messrs I. S. Agre and I.S. Mittra.

The author also wishes to acknowledge the help of the staff at Gulmarg Research Observatory for the facilities provided.

Yoj Prakash Shukla
7.9.55

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CHAPTER. I.

Introduction.

Historic Review.

The use of photographic emulsions for the study of radioactive properties was shown for the first time by Mugge in 1909. This was followed by the experiments of M. Reinganum, who showed that if alpha particles strike a photographic plate at glancing incidence they effect the silver bromide grains in a way similar to light. Kinoshita reasoned that the photographic action of alpha particles is due to ionization of silver halide molecules in the grains. Inspired by the discovery and operation of Wilson Cloud Chamber, Reinganum, W. Michl, F. Mayer, Ikeuti and many others tried to make refinements in this technique of registering the tracks of different particles, untill in 1925 M. Blau showed that protons could also produce tracks similar to alpha particles. In 1927 Myssowsky and Tschishow pointed out that use of thickly coated emulsions would make it possible to get longer tracks. They prepared emulsions upto the thickness of 50 microns and even more.

Blau and Wambacher discovered a sensitising material called Pinacryptal Yellow which could make emulsions sensitive to high energy protons. They also studied the photographic process of detection of protons by measuring the density of silver grains as a function of ionizing power of the rays. They noticed that the grain density was independent of the range for air range of 2cm or less. The experiments with alpha particles also showed similar results.

The work on photographic emulsions sensitive to high energy protons without using sensitising material was taken up independently by A. Jadnov and by others at Ilford laboratories. Jadnov showed that the nature of the tracks produced by nuclear

particles depends on the size of the grains and on the concentration of silver bromide in the emulsions. Thus to get good proton tracks the grain diameter should be 0.5- 0.8 microns.

The basic and most important property of emulsion technique is its continuous sensitivity. We can consider the emulsion just like a continuously acting cloud chamber which makes a permanent record of all events occurring. Besides the emulsions are cheap and easy to handle. Though the technique is subject to many limitations like 'fogging', 'fading of the latent image', 'straggling' etc. yet its potential powers were fully recognised by the year 1930. Its use was restricted due to lack of precision in the measurements of energies and mass etc., until C.F. Powell³⁻⁶ showed that the energies of the tracks could be determined accurately from their residual ranges under proper experimental conditions. This was applicable both to protons and alpha particles. Even the energies of the neutrons could be measured accurately by considering the knock-on protons within proper cones. By the end of the second world war Powell and his collaborators had established that photographic emulsions were a versatile method capable of giving results of high precision and reproducibility and this technique became one of the most important for the study of nuclear events.

Characteristics of the emulsions.

It is clear from the above that emulsion should not only register the paths of particles but should be able to help in accurate determination of mass, charge, energy and momentum^{2,7}. Thus main requirements of the emulsions are (1) tracks should be produced by all charged particles; (2) tracks should be sufficiently clear above the background fog; (3) the tracks of different mass and charge should differ in appearance so that the identification task may be

easy; (4) background fog should be minimum.

The above requirements are controlled through many factors ~~factors~~ viz. the concentration of silver halide, mean grain size, mean grain spacing and sensitivity. Sensitivity is defined as the probability that a silver halide grain struck by an ionizing particle becomes developable. It depends on two factors: (1) the energy spent in a grain by an ionizing particle which depends on the charge and velocity of the particle and (2) the distribution of the sensitivity specks throughout the emulsion. Demers⁶ has shown that the average grain density can be written as:-

$$n = \frac{3}{2} \frac{c P}{\rho d}$$

where c is the concentration of silver halide, ρ its density, d is mean grain diameter and P the probability that a silver grain struck by an ionizing particle becomes developable. Since P is a function of d it can be assumed that within proper limits P is roughly proportional to d^3 . All these interdependencies make it difficult to meet all the requirements by a single emulsion e.g. for recording relativistic particles the sensitivity should be increased and emulsion should have large grains, while for low energies the grain size should be small and sensitivity should be less. To obtain clear tracks the grain spacing should be less and their size should be small. Hence a compromise is made in different factors in order to meet all the requirements. Apart from all this the emulsion should be sufficiently thick and of uniform composition.

In view of the above requirements the emulsions were prepared by M/s Ilford Ltd. and Kodak Ltd. in England and Eastmankodak in U.S.A. Ilford introduced the emulsions and first being R₁ plates which were insensitive to protons. These were followed by proton sensitive R₂ plates. Sometime later Agfa introduced much improved

plates - K- plates - which could register the protons of much higher energies. Now a days a series of emulsions have been put forward by the above mentioned companies. The general characteristics of the most common emulsions are given in Table I.

T A B L E I.
(Characteristics of the common emulsions.)²

Emulsion	Ilford				Kodak			Eastmankodak			
	D ₁	C2	B2	G5	NT1a	NT2a	NT4	NTC	NTA	NTB	NTB
Mean grain dia. (micron)	0.12	0.16	0.21	0.16	0.19±0.04	0.22±0.04	0.39±0.04	0.1-0.3	0.2-0.3	0.2-0.3	0.1-0.3
Highest vel. detected (v/c)	0.2	0.31	0.46	all	0.2	0.35	all	---	0.15	0.49	0.1
Highest detectable energy of electron	---	0.03	0.07	all	---	0.1	all	---	---	0.08	0.1
Highest detectable energy of muons	---	5.5	0.14	all	2	20	all	1	16	16	8
Highest detectable energy of protons	---	50	120	all	20	200	all	---	10	150	750
Highest detectable energy of neutrons	---	100	240	all	40	400	all	---	20	300	1500
Highest energy of alphas	1500 low		all	all	500	all	all	low	250	all	all

All these emulsions have practically the same silver halide concentration but differ only in grain size and sensitivity. The composition of dry emulsion in grams/cm³ is given in Table II. For G5 emulsion the bromine and iodine contents are 1.496 and 0.026 grams/cm³ respectively.

T A B L E, II

Composition of dry emulsion.

Element	Ilford	Kodak	Eastmankodak
Silver	2.025	1.97	1.70
Bromine	1.465	1.44	1.22
Iodine	0.057	0.039	0.054
Carbon	0.30	0.27	0.34
Hydrogen	0.049	0.038	0.043
Oxygen	0.20	0.16	0.17
Sulfur	0.011	...	...
Nitrogen	0.073	0.080	0.11

Zadnov (1955) showed that grains per unit path length (100 microns) of undeveloped emulsion can be expressed by the equation:

$$g_{\max} = \frac{150}{d} C \quad \text{grains per 100 microns}$$

where C is fractional volume concentration of silver bromide (about 0.5 for the new nuclear emulsions) and d is average grain diameter in microns, the grain being assumed spherical. Approximate value of the grain size and g_{\max} is given in Table III. These values have been given by Dodd and Waller (1951)¹¹, Webb (1948)¹², Knowles and Demers (1947)¹³, and Winand (1948)¹⁴.

T A B L E III.

(Approximate grain size and g_{\max} in nuclear emulsions.)¹⁵

Emulsions	Average grain diameter microns	Average density g_{\max} grains per 100 microns
Kodak NT4	0.4	176
Ilford G5	0.27	275
Eastman NTB	0.25	300
Ilford C2	0.18	400
Demers II	0.06	1200

The properties and sensitivity of Ilford G5 emulsion have been given by Dodd and Waller (1951). Apart from other properties the minimum grain density of about 36 grains per 100 microns has been

shown for a fully developed normal G5 plate. Since the beginning of the year 1952 the G5 emulsion has been improved upon and a minimum grain density of 45 grains per 100 microns has been found with an efficiency of about 17%. Herz and Waller (1952)¹⁵ has introduced another modified emulsion called G0, which has all the properties of G5 except that the sensitivity is such that only heavily ionizing particles are recorded.

Sensitivity of nuclear emulsions show a considerable variation with temperature at the time of exposure. This variation has been studied by Dilworth (1949)¹⁶, Dollman (1950)¹⁷, Lord (1951)¹⁸, and Coats & Herz (1949)¹⁹. They have shown that tracks of heavily ionizing particles show a marked decrease in grain density below 0°C, on the other hand the minimum ionizing tracks show no significant variation in the grain density between room temperature and -80°C in the case of Kodak NT4 emulsion, and in the range of 20°C to -50°C for Ilford G5 emulsion. Lord has reported that the emulsions lose practically all its sensitivity at -200°C.

An empirical relation showing the variation in grain density with exposure temperature has been given by Beiser (1951)²⁰:-

$$n = A \exp(-E_1/kT) (1 - a \exp(-E_2/kT)).$$

where n is the grain density, T the exposure temperature, A is a function of sensitivity of emulsion and rate of energy loss. a , E_1 , E_2 are constants depending on the emulsion. The first exponential may interpreted as being proportional to the rate of arrival of silver ions at the sensitivity speck and second as the relative number of ions released from the speck. The curves given by various workers indicate that optimum temperature for exposure lies near about 20°C.

Application to Cosmic rays and Nuclear Physics.

In the study of cosmic rays the emulsion technique was first employed by Wilkins, when in 1936 he sent Ilford R2 plates by

means of balloons to high elevation and registered some high energy alpha tracks. Rumbaugh and Locher sent some plates high in the atmosphere, covered with paraffin and thus confirmed the presence of neutrons in cosmic radiation. They showed that at the height of about $\frac{1}{2}$ meter water equivalent from the top of the atmosphere the neutron constituted a considerable fraction of cosmic rays. Schopper used Agfa K plates and Ilford R5 for similar type of experiments on cosmic ray neutrons.

Blau & Wambacher observed cosmic ray stars in emulsion plates. These stars represent the nuclear disintegration, some times far more energetic than commonly observed in the laboratory. Wambacher studies on the stars by grain count and range method showed that total disintegration energy was more than 60 mev in most of the cases - going upto 150 mev - if contribution towards neutral particles is neglected. Further work on stars was carried out by Fillipov, Jadnov etc. using E3 emulsions and as a result the stars were classified in two groups; (1) disintegrations where particles are distributed in random directions from a common centre and (2) where the group of tracks from a common origin are within a relatively small solid angle. The latter was named as proton shower. Steller studied the altitude dependence of these stars and found that the radiation responsible for the production of stars is strongly absorbed in air. All this helped in understanding the nature of this radiation and in forwarding adequate theories for the formation of stars. This in turn threw some light on the range of nuclear forces. Hardinge et al (1949)²⁴ found the value of range of nuclear forces to be 2×10^{-13} which is in good agreement with the values found by means of other experiments.

But the most outstanding discovery with emulsions during the last few years was that of the π -meson, (Occhialini and Powell, 1947²¹; Lattes et al, 1947²²) of mass $276 m_e$. The discovery of π -me

has brought another advantage of emulsion technique that it can be applied to the study of very shortlived phenomena. Due to the high stopping power of the emulsions (about 1,560 times that of the air) the short lived particles of particular energy can be brought to rest before decaying which otherwise would have decayed in flight in the gas. This technique thus offers a nice method for the study of the effects at the end of the range. The lifetime of the particle can be estimated by measuring the total range traversed by the particle. By this method the life time of π - meson was found to be 6×10^{-9} seconds (Camerini et al, 1948)²³.

In the last few years the emulsion technique has brought forward the possible existence of many unstable particles viz. T , Kappa meson, χ meson, charged v , S particles, Y events and neutral v (Λ^0) etc. with mass values either between a π -meson and a proton (most of the particles have mass about 1,000 m_e) or above that of a proton. These particles have been observed to follow different decay schemes, but the evidence on some of them are still inconclusive. These rare events are being sought near the top of the atmosphere by means of balloons.

This technique has also been used very successfully for the study of primary cosmic rays which consists of heavy nuclei near the top of the atmosphere. These heavy nuclei undergo various types of collisions with air nuclei (Bradt & Peters, 1949²⁵; Brown et al, 1949²⁶) some times causing big nuclear explosions and sometime passing through the target nucleus by only ejecting some nucleons. Many striking results ~~results~~ have been obtained by sending the plate sensitive to minimum ionization to balloon altitudes. This technique has thus revealed the nature of cosmic radiation much more efficient than any other existing technique,

Apart from the use of this technique for the study of various cosmic ray phenomena the technique has also been used for various problems of nuclear physics e.g. to determine the energy spectra, to measure cross-section, to estimate half life etc. Various nuclear disintegrations and their products have been very frequently studied with emulsions. Neutrons have been studied by registering recoil protons. These methods have revealed as many as fifteen velocity groups for neutrons from Beryllium within the velocity range of 10^9 to 5×10^9 cm/sec. Taylor expected that the disintegration of Boron with slow neutrons will follow the reaction as ${}_5\text{B}^{10} + {}_0\text{n}^1 = {}_3\text{Li}^7 + {}_2\text{He}^4$ and not ${}_5\text{B}^{10} + {}_0\text{n}^1 = {}_2\text{He}^4 + {}_2\text{He}^4 + {}_1\text{H}^3$, and since only one track was found in the plate the former was concluded to be correct. Also the possibility of recording the lengths and orientations of all products of disintegration simultaneously makes it possible to verify the laws of conservation of energy and momentum. The satisfactory results justify the use of this method for the determination of energy and momentum of neutral particles, which may be emitted in some reactions and which do not leave observable tracks in the emulsion (Lattes and Occhialini, 1947)²⁷.

Wilkins and Dempster identified the radioactive isotopes of Samarium with the help of these plates. Emulsions were also used for the study of fission process by Myssowsky and Jdanoff (1939)²⁸, Tsein (1947)²⁹ and many others. The point of origin of any particle relative to fission ~~gka~~ fragments gave an estimate of the time interval between fission and the emission of that particle Demers (1956)³⁰.

The developement of electron sensitive emulsions have made it possible to study various nuclear physics problems in the high energy region. Recently the mesons produced in Berkley Cyclotron

were recorded in emulsion plates. Various properties of mesons e.g. life time of π and μ , their capture cross-section in many substances as well as their reactions have been studied very accurately with this technique.

The technique of emulsions is being increasingly employed in other branches of science viz. Biology and Medicine.

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CHAPTER II.

Description of apparatus.

Considering the utility and importance of emulsion technique the department of Physics at Aligarh has recently started a nuclear emulsion section. The equipment consists of Cooke Research microscope of M4000 series with binocular bodies fitted with protractor ocular and a mechanical stage with two micrometers having the least count of 5 microns. The fine focussing mechanism is also graduated in microns. The optical equipment consists of various types of eyepieces and objectives with graticules and stage micrometers. For photomicrography, we have extensible plate camera outfits as well as 35 mm camera adaptor with a Leitz III-F camera to be used with the latter. The photographic equipment includes a 4x6 Omega enlarger, a Wasp copying unit and a large number of small accessories. For controlling the temperature of solutions during the different stages of development of thick emulsion plates, we have a large cooling plant with thermostatic switches where the temperatures can be controlled within $\pm 2^{\circ}\text{F}$. We have also other facilities like a cold storage etc.

Powell (1943)² emphasized the importance of the optical equipment for accurate results and for relieving the nervous strain on the observer. The new concentrated emulsions, themselves, have quite a good contrast of the track above the background so that there is no special fatigue on the observer. Moreover the use of binocular microscopes with inclined eyepieces have also some advantage in reducing the strain on the observer. Powell¹ recommended the use of microscope objectives of high numerical aperture because of their small depth of focus with the result that visible background of grains is reduced as compared to the objectives of

lower aperture. The use of oil immersion objectives has the advantage over air objectives that the refractive index of the emulsion is sufficiently close to that of the immersion oil which ensures the fineness of optical quality of the image of grains lying deep in the emulsion. Powell used the oil immersion objectives in conjunction with high quality substage condenser with a maximum numerical aperture of 1.30. The use of 3 mm apochromatic objectives (numerical aperture 1.30) has been found to be most advantageous. This objective has a magnification of 60 and working distance of 0.25 mm.

One disadvantage of high power objective is very short working distance. For example the 2.2 mm apochromatic objective (N.A. 1.32, magnification x80) has a working distance of only 0.12 mm which will allow the observation of the emulsion upto 250 microns even if the shrinkage is taken into account. Cooke Troughton & Simms have produced 3.75 mm oil immersion fluorite objectives (numerical aperture 0.95, x45) with working distance 1.5 mm without at all effecting the optical quality of the image. This will allow the use of even thickest emulsions produced and employed at present.

Champion and Powell (1944)³ have accounted another disadvantage of high power objectives. This is the curvature of the field of view. This means that a track parallel to the surface will not have all grains in focus at the same time. Proper attention is to be paid to this defect in measuring the angle of dip which should either be made at the same spot of the field of view or on grains equidistant from the centre.

In our studies we have found 4 mm apochromatic objective not to be much suitable for nuclear emulsion work because its performance depends critically on the cover glass thickness,*

While measuring the dipping tracks the change in the vertical direct may be taken as a variation in cover glass thickness, starting from zero as minimum. The use of 3.75 mm flourite objective is highly recommended in this connection because as being an ~~in~~ oil immersion objective the question of a cover glass does not arise. Moreover this has a large field, a high numerical aperture, a good depth of focus, and a long working distance. Out of various condensers (abbe, aplanatic, achromatic dry and achromatic oil both short and long focus) tried the use of achromatic condenser M 1386 is highly recommended as a general purpose condenser specially for use with apochromatic and flourite objectives. The last two types of condense have not been found suitable because of their short clearing distances.

The Cooke Research Microscopes have also been provide with rotating stages which are highly useful for the measurement of coulumb scattering of the tracks in the high energy region.

The thermostatically controlled cooling cabinet has three tanks and every one of them can be controlled at any temperature within the range of 20°F to 80°F with an accuracy of $\pm 2^{\circ}\text{F}$. The tanks are well insulated and the fall or rise of the temperature ~~does~~ due to conduction or radiation is very slow. Each tank has a dial thermameter to indicate the temperatures and a motor driven agitator to keep the temperature uniform in the whole tank.

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National Academy of Siences, Allahabad, (India) in February, 1954.

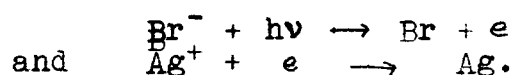
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C H A P T E R I I I .

Processing of plates.

Formation of latent image.

Various theories have been put forward for the formation of image on a photographic plate - called latent image. An exposure of silver bromide (AgBr) or silver chloride (AgCl) to light produces free silver and halogen. There is no evidence that any intermediate chemical substance like a sub-halide is ever formed by the action of light. The general reaction can be given as:-



where $h\nu$ is the quantum of light and e is the electron.

The production of latent image by an ionizing particle along its path in nuclear emulsion follows basically the same process as occurs in ordinary light sensitive plates. The only significant difference lies in the manner in which the ion pairs are formed in the two processes. In the former they are formed by the electrostatic interaction between the charged particle and the electrons of the atoms in the emulsion, while in the latter they are formed by the photoelectric emission of electrons by incident photo

There is no chemical evidence for the presence of silver in the latent image. It is however clear that the latent image is formed by silver atoms. The latent image is destroyed by the action of strong oxidising agents. It has been established that the sensitivity increases by the addition of silver sulphide (Ag_2S) nuclei. This shows that there is some relation in sensitivity and Ag_2S nuclei. The spectral analysis has made it clear that Ag_2S does not act as light absorbing centres and hence it should not have any bearing on sensitivity. The change of sensitivity is due to the fact that Ag_2S brings about a change in the distribution of silver atoms

formed by the action of light. It is suggested that \blacksquare Ag_2S acts as the concentration centres for photolytic silver.

The theory of formation of latent image was first put forward by Webb. The absorption of a quantum of light by silver halide grain is followed by the transfer of electron to conductance band. These electrons move through the crystal for large distances untill they are trapped in the regions of impurity. Thus the electron may be trapped in entirely different position than where the light quanta was absorbed. According to this theory the latent image is identified by the electrons trapped at the sensitivity specks. But no mechanism was given as to how Ag^+ ~~XXXX~~ neutralises the electrons. Moreover the dependence of the sensitivity on the exposure temperature could not be explained on the basis of photoconductance. Gurney and Mott (1938) gave first comprehensive theory on the basis of electrical conductivity.

This theory can be divided in two parts ; (1) the primary electronic process associated with the photoconductance and (2) the ionic process dealing with the migration of the silver ions. The first process is exactly similar to that given by Webb⁵ where the electrons are trapped at the sensitivity specks. The electrostatic potential thus created brings about the second process. The silver ions are attracted to the negatively charged specks and migrate towards them. Thus at the sensitivity speck the silver atoms are formed by neutralization.

The validity of the theory can be tested by seeing the photographic process at low temperature. At low temperature migration of interstitial ions is negligible, thus the ionic process becomes separate from the electronic process causing a decrease in the sensitivity.

It is suggested that latent

It is expected that latent image formation in nuclear emulsions is very much less efficient than photographic emulsion due to time that are taken by the former for the utilisation of electrons. One of the reasons for this inefficiency is the short times needed for a particle to traverse each grain e.g. a 5 mev alpha particle will traverse the grain in about 2×10^{-14} seconds. Since the migration of silver ion is much slower than electrons, the sensitivity specks acquire the negative charges much rapidly than they are neutralised and thus further electrons are repelled unless a sufficient number of Ag^+ ions reach the speck. This effect is unimportant for weakly ionizing particles.

The theory can also explain the change in specific energy loss for G5 emulsions, as given by Fowler and Perkins (1951). The curve given by them is shown in figure 1. Here the grains per 100 microns are given against the specific energy loss. It shows that the specific energy loss of particles at various points is directly proportional to grain density, but the proportionality does not hold for high energy losses, e.g. the emulsion sensitivity decreases for specific energy losses above a certain threshold.

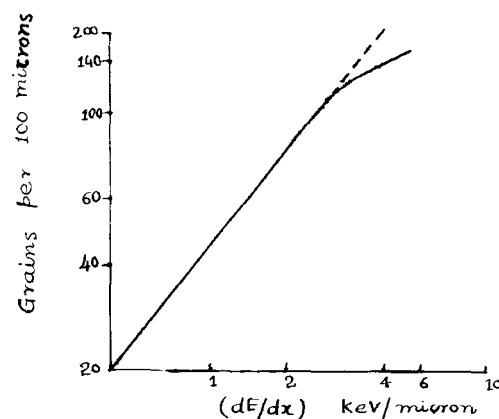


Fig 1

(Grain density in G5 as a function of energy loss (Fowler & Perkins, 1951))

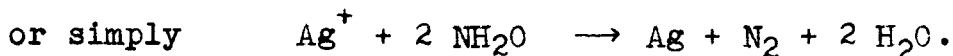
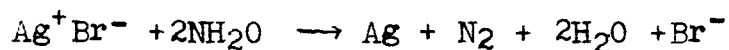
This is due to the inefficiency of electron utilisation i.e. the electrons enter the sensitivity speck more rapidly and create a space charge, consequently the specks do not accept any further electrons until the space charge is neutralized by recombination. The linear part of the curve shows that the rate at which the electrons are entering the speck is proportional to the rate at which they are being neutralised. For density above 200 grains per 100 microns

the saturation occurs and it is no longer linear.

The fate of halogen is not clearly defined in the theory of Gurney and Mott, but it is generally assumed that it escapes to the surface and gelatin acts as halogen acceptor.

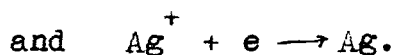
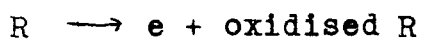
Mechanism of developement.

Generally in the process of developement the individus silver halide grains are reduced to metallic silver, while the developer itself gets oxidised. The simple mechanism of developement of AgBr grains with Hydroxylamine is shown by the following reaction



The reaction of other developers though much more complicated is fundamentally the same. In the developement process the reduction starts only at discrete points i.e. at the points of latent image and proceeds till the whole grain is reduced. In general the reduction will not spread from one grain to another - where the latent image is not there- unless there is a physical contact in the two or such a contact is made during the developement.

Basic mechanism as how a latent image (or the presence of a silver nucleus) helps in the reduction of whole grain may be given as follows. It is assumed that developer gives electrons to the silver nuclei and the nucleus then acts as tiny electrode where the whole silver ion gets reduced. The reduction thus includes ~~in~~ two steps (1) transfer of electrons to silver and (2) neutrilization of silver ions by electrons.



where R shows the developer and e stands for the electron. The

question why the direct transfer of electron to Ag^+ does not take

place, may be explained in terms of the f activation energy. The activation energy of direct transfer is much larger than for a process given above.

Thus all the developers are reducing agents which reduce the silver halide and ~~if~~ themselves get oxidised. Apart from it the developer also contains alkali, sulphite and bromide. The function of alkali is to adjust hydrogen ion concentration. Thus it maintains the p^H of the developer to a constant value, because the increase in p^H would mean an increase in the rate of development. Sulphite dissolves the oxidised products of the developer which if allowed to remain there would have undesirable influence on the rate of development. Generally oxidised products get decomposed in the presence of alkaline solution and products are coloured materials which are most efficiently carried away by Sodium Sulphite. Bromide (generally used as Potassium Bromide) is added as fog resistor and as an aid to uniform development.

Processing of thick emulsion plates.

The development of thick emulsion plates is the most important part of the emulsion technique and if proper attention is not paid to it, this may lead to serious errors. Since all these emulsions have a considerably high ratio of silver halide to gelatin, special methods are to be used for their development. The basic problem here is to develop exposed emulsion grains without a corresponding development of unexposed grains or 'fog' grains. Moreover if ordinary development methods are employed the developer is more at the surface than at the bottom and this causes a great difference in the development of different layers of thick emulsion. Proper attention should be paid to avoid this ununiformity of development, because the variation in grain density with the depth

of the track caused due to this reason will create a great difficulty in the interpretation of results. Hence, in short, the conditions for the processing of thick emulsions may be laid as: (1) it is necessary to adjust the rate at which the developer is supplied to emulsion grains against the rate at which the products of development diffuse from the layer. (2) all the layers of emulsion should have same degree of development. (3) during the development the emulsion should not swell or shrink unduly and it should not reticulate too. p^H , salt content and temperature of the developer are the main factors to control this requirement and, therefore, rapid change in any of the above factors should be strictly avoided at any stage of the processing. The rapid change of temperature and p^H should also be avoided in stop bath, fixing bath, and washing operations.

Generally all these requirements are met through physical factors rather than chemical ones, i.e. by controlling the temperature or by increasing the time of each operation, with the result that whole process takes quite long times e.g. the total time taken by 600 micron plates is ~~quite~~ about 248 hours in all.

The above requirements form the following requisites of a good developer⁴:-

- 1) Resistance to oxidation by air.
- 2) Low alkalinity- strong alkalinity causes swelling of the emulsion and consequently severe distortions are caused during the hot stage.
- 3) Low concentration- the high concentration of the developer will precipitate at low temperature.
- 4) Simplicity- many agents in a developer are not recommended if the rate of penetration and temperature coefficient of various agents differ too much.
- 5) Good buffering.

- 6) High bromide sensitivity - for reducing the fog and stain.
- 7) Little solvent action on silver halide.

These requisites need a developer of moderate or high temperature coefficient which may penetrate quickly through the emulsion and may remain stable at high and low temperatures. The p^H of the developer should preferably be close to that of the emulsion.

Various methods were tried for development of thick emulsion plates, but the most efficient is the temperature cycle method given by Dilworth et al (1948)². The principle underlying this method is that the developer is first made to penetrate throughout the whole thickness of emulsion at the low temperature ($\leq 5^{\circ}C$). At this temperature no development takes place, then the temperature is raised and actual development takes place. A proper consideration of the concentration of the developer is to be kept in this stage. The stopping of the development starts at high temperature and then it is again brought down to low region. Then the fixing starts at low temperature and is finished at a high temperature. In all the operations it is to be strictly kept in mind that no rapid change of temperature takes place.

Blau and Defelice (1948)⁷ put forward a two bath method for the development of these emulsions. In this method the developer is divided in two baths. The first bath has a part of Sodium Sulphite, Potassium Bromide, but no alkali, while the second bath has all necessary parts of a developer plus an additional amount of alkali. In first bath the alkali diffuses in the emulsion but the rate is too low due to the lack of alkali. The actual development takes place in the second bath. Here the whole process can be accomplished at ordinary temperatures. Though the danger of

reticulation ~~was~~^{was} removed as the temperature was constant, yet the method could not gain favour because of its inapplicability of uniform developement of thicker emulsions.

Generally the temperature cycle method of developeme has been used by various workers viz. Wilson & Vaneslow (1948)¹, Dainton, Gattikar & Lock (1951)⁸; A.J.Herz (1952)⁹; K.R.Dixit (1952 & 1954)¹⁰⁻¹¹; B.Summerfield (1953)¹²; Dilworth et al (1951)³; Stiller etal (1954)¹³ etc. for processing of thick nuclear emulsion plates. Plates upto 1,000 microns have been developed with this method, Various developers e.g. Amidol; ~~Amidol~~ Amidol-bi-sulphite; Azol; D19b etc. have been used. Table IV gives the composition of various developer

T A B L E IV .

Composition of various developers and p^H at room temperatu

Name	D19b	Azol	Amidol-bi-sulphite	Brussels' group	Amidol	Dixit
Agent	metol hydroqu -inone	para- amino phenol	p- diamino phenol	-----	p- diamino phenol	metol
For-metol mula	12.2	Azol 16	Amidol 3.0	Amidol 4.5	Amidol 3.0	Metol 3.
Hydroqui. 8.8		1%KBr 88 ml	Anh.Sod. Sulphite 6.7	Anh. Sod. Sulphite 18.0	Anh. Sod. Sulph. 12.0	Sod. Su -phite
Sod. Sul- -phite	72	water 384ml	Sod. bi. Sulph. liqu. 1.4 ml	1%KBr 8ml	Water 1000 ml	water 10 ml
KBr-	4.0		Water-930 ml	Boric Acid 35 gm		Sod. Car 50 gr
Sod. Carb. 48.0gm				Water 1000 ml		Sod. bi. carb.50
Water	2000 ml					water 10 ml
p^H	10.0	11.5	6.7	6.4	7.2	9.2

Dainton, Gattikar & Lock⁸ have made a comparative stud

of various developers for the following properties.

(1) Penetration characteristics- Payne has shown that rate of penetration of any developer increases by decreasing the p^H . The time of penetration is generally reduced by about 40% by presoaking the plate in distilled water. It was found that Amidol and Amidol Bi-Sulphite are equivalent in penetration and take much less time than Azol and D19b. The penetration time (T) can be expressed by an empirical formula as :

$$T = K. t^x$$

where t is thickness of the emulsion , x is of the order of 1.4 and K is constant for a given developer at a given temperature.

(2) Temperature Characteristic. The change of activity of various developers with temperature was seen and it was found that the rate of action changes very rapidly with temperature. D19b was found to be more sensitive than other developers. Azol, though quite sensitive to temperature, has a low activity.

(3) Stability of various developers was also tested upto 27°C., and all of them have been found to be perfectly stable at high as well as at low temperatures.

Apart from it the background properties and staining properties of various developers were also tested and all the above information indicated Amidol to be an ideal developer for development of plates upto 400 micron thick. Above this Amidol Bi-Sulphite should be used. The formula given by Brussel's group makes a fine substitute for Amidol Bi-Sulphite.

Development Process.

Plates are first soaked in distilled water at room temperature and then it is slowly cooled to 5°C., and maintained at

that temperature for the required time. This time varies with the thickness of the emulsion. The plates are then transferred from 5°C water to 5°C developer and they are allowed to stay there for some time. Then, generally, either of the following methods is followed:-

I. Hot bath method. The concentration of the developer is atleast halved and then temperature of the whole bath is raised to about 18°C. No agitation is to be done at this stage. This temperature is maintained till the whole development is over.

II. Hot plate method. The plates are taken out of the cold developer and the excess of the developer is wiped off gently with a filter paper. The plates are, then, placed on a dry surface with glass downwards and the temperature of the surface is raised to about 27°C and maintained there for required time. In this method the developer which has penetrated in the cold stage is sufficient to develop the whole plate uniformly and there is no overdevelopment at the top. An accurate temperature control should be had in this method and a perfect thermal contact is required in the plate and the surface. This method has been found more satisfactory than the first one.

The plate is then transferred from hot stage to stop bath. Out of many reagents used as stop viz. ½% HCl; 5% NaHSO₃; 1% KBr etc. Acetic Acid (0.5-1.0%) proved the best. The temperature of the stop is brought near to that of the hot stage and the plates are transferred. The temperature of the whole bath is brought down to 5°C. The plates are kept till whole development is ceased. In the whole process the plates are placed horizontal and this is very important for thick emulsions.

Plates are then fixed in the solution of Sodium Thio Sulphate and various workers have used various concentrations.

Frazinetti has given 40% hypo solution to be the most satisfactory value of concentrations. The Ammonium Thio-Sulphate is a rapid fixing agent and, therefore, some workers have recommended the addition of Ammonium Chloride to hypo solution with a view to reduce the fixing time. But such fixing baths have the tendency to remove some of the developed grains near the surface of the emulsion and the effect is more pronounced in the case of thick emulsions. Hence the addition of Ammonium Chloride is not favoured. Anyhow the addition of Sodium Bi-Sulphite to hypo solution reduces the stains etc. The best fixing bath is prepared by adding 30 gm of Sodium Bi-Sulphite to a litre of 40% hypo solution.

The plates are transferred to a hypo bath at 5°C and then the temperature is raised to 19°C. The whole of the fixing can be completed at this temperature. The plates are to be perfectly horizontal and a little agitation is quite useful in this stage. In this connection the method adopted by Dixit (1952)¹⁰ is most advantageous. He has preferred the agitation caused by the convection currents to the mechanical agitation. For obtaining this he varied the room temperature by 2°C, and the convection currents thus caused gave a perfect agitation to hypo without at all effecting the plate.

Washing is done either with slowly running water or the water of the dishes is changed after small interval of time. This stage is most critical for thick emulsions because most of the distortions are caused in this stage. Herz and Edgar (1953)¹⁵ have remarked that if all the operations are performed at low temperature ($\sim 5^{\circ}\text{C}$ - 7°C) the chances of distortions are reduced to minimum.

Before putting the plates for drying, the soaking of the plates in the solution of Glycerine for about 1 hour is very usefull. The concentration of the glycerine can be chosen between

1-2%. This helps in preventing the stripping off of the emulsion after drying. The drying is to be started with 100% humidity in gentle air. The latter ~~xxx~~ requirement can be achieved by means of a 25 watt electric bulb at a distance of few feet from the plates. The circulation of the air caused by this is sufficient for the purpose. Dilworth et al (1951)³ have pointed out that edges of the plates usually dry up first, causing a surface distortion in the emulsions. This can be remedied almost completely by surrounding the plate by a 'guard ring' of similar plates edge to edge which results in more even drying.

Experimental details and data.

We have tried various methods for the development of nuclear emulsion plates. Generally the temperature cycle method was adopted in all cases. Plates upto 600 microns have been successfully developed in our laboratory. We have tried Azol, D19b, Amido Brussels group developer and Dixit's formula. We could not try Amidol Bi-Sulphite because Sodium Bi-Sulphite (liquor, Sp. gr. 1.3 which is a special product of B.D.H. was not available. Out of all these developers tried we have also found Amidol to be best for plates upto 400 microns and above this Brussels formula makes a nice substitute for Amidol Bi-Sulphite. Dixit's method is also quite satisfactory so far as the development of 200 micron plates is concerned but the time taken by 400 micron plates is too long. Moreover the satisfactory development of 400 micron plates depends on the softening of gelatin which is not an easy requisite to fulfill. We have measured the variation of p^H in case of Amidol and Dixit's method with the variation ~~of~~ in temperature and these are shown in Table V.

T A B L E V .

The variation of p^H with temperature for Amidol & Dixit's formula.

Temperature deg. C.	Amidol	Dixit's method
4	6.93	9.160
8	7.01	9.160
12	7.08	9.179
16	7.14	9.181
20	7.24	9.210
24	7.32	.....
27	7.50	9.220

The Amidol is well within acidic region at low temperature ($\leq 5^\circ\text{C}$) and at high temperature it goes to alkaline region (since p^H is more than 7.0). This is most important factor in its use because penetration is the property of acidic region while, the actual development takes place in the alkaline region. Thus at low temperature only penetration of the developer occurs while the development takes place in hot stage. This property though not exhibited by Dixit's formula, yet the p^H is not varying too much and we can depend on it low thicknesses of emulsions. As an example Table VI gives the times of development of 200, 400, and 600 micron thick emulsion plates with Amidol, Azol, Brussels group method and Dixit's method, used by us.

Presoaking of the plates, though decreases the time of penetration of the developer, has not been recommended by Wilson & Vaneslow; Blau & Defelice. They have found that presoaking increase the background fog. Our results ~~at~~ of development show that though presoaking increases some fog grains, reduces the possibility of distortions which may otherwise have been created due to longer time.

We have found that use of clearing solution (Stiller et al, 1954)¹³ in case of plates thicker than 400 microns is very advantageous. Clearing solution consists of :

T A B L E VI.

Development times of various thicknesses in different dev

	Amidol			Azol		Dixit		Brussel's		
	200	400	600	200	400	200	400	600		
Soak in water	25 m	90 m	120m	25 m	90 m	....		100 m	150 m	
Developer at 5°C	25 "	90 "	120"	90 "	120"	40 m		100 "	150 "	
Hot plate at 27°C	25 "	30 "	30 "	...	...	....		20 "	180 "	
Hot bath at 18°C	...	...	...	105"	105"	39 "		...	....
Stop	20 "	90 "	120"	45 "	90 "	15 "		100 "	150 "	
Fixing	12 h	60 h	70 h	5 h	24 h	15h in I 15h in II		60h	105 h	
Washing	12 "	60 "	72 "	12 "	60 "	12"		24 "	36 "	
Drying	12 "	60 "	100"	12 "	60 "	12"		....	....

Ammonium Acetate- 15.0 gm.; Citric Acid- 5.0 gm;

Thiourea - 5.0 gm ; Water- 500 ml.

and 600 micron plates are put for about 24 hours in this solution before proceeding to washing stage. This removes the stains etc. the plates are remarkably clear. The concentration of hypo should be gradually reduced when washing starts. Apart from clarity the plates are uniformly developed and are free from surface distortion. We have carried out all the post development operations at low temperatures ($< 8^{\circ}\text{C}$) and the agitation was given by the convection currents caused by the variation of the temperature. Dish washing was preferred to running water and the ~~water~~ water was changed after small intervals. The use of guard ring was made in the drying process.

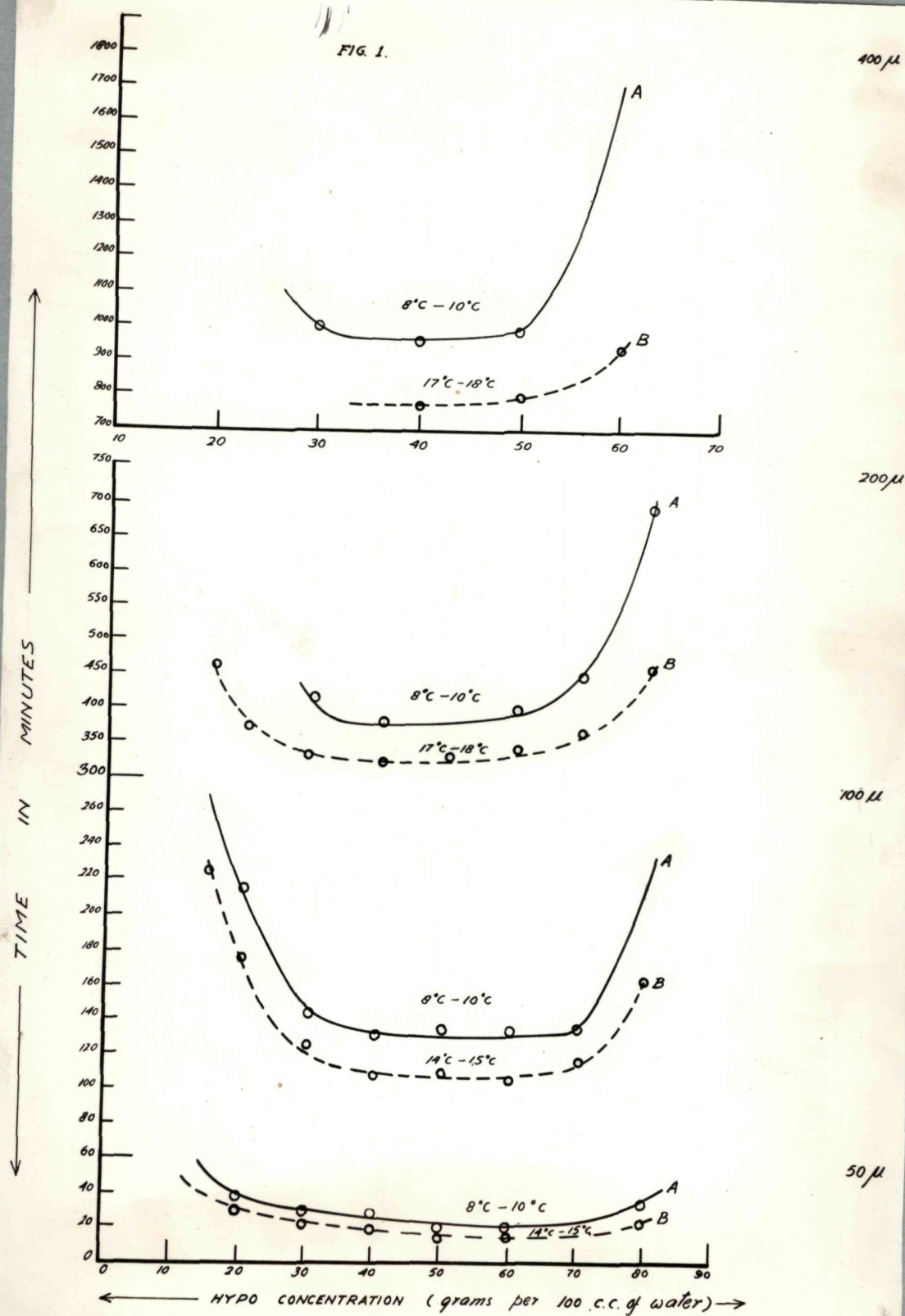


Fig. 2. Variation of clearing time (in minutes) with the hypo concentration (gms. per 100 cc of water) for different thicknesses of emulsions-.50, 100, 200, and 400 microns. Curves A and B represent the variation for each thickness at temperatures of $(9 \pm 1)^{\circ}\text{C}$ and $(15 \pm 1)^{\circ}\text{C}$ respectively.

Effect of hypo concentration on clearing time of thick emulsions. **

Sheppard, Elliot and Sweet (1923) and others have shown that at a given temperature the clearing time depends on the concentration of Sodium Thio Sulphate (Hypo) in a typical manner. There is a sharp decrease in the clearing time for lower concentration and a rapid increase at higher concentrations. Their work, however, was confined to thin emulsions only. In view of the fact that no similar study in the case of thick emulsions seem to have been reported, and that various workers have used different hypo concentrations, viz. 30% by Wilson & Vaneslow (1948)¹; 40% by Dainton, Gattikar & Lock (1951)⁸; Stiller et al (1954)¹³; 28-30% by Dixit (1952, 1954)¹⁰⁻¹¹, it was considered worthwhile to make a systematic analysis of the effect of hypo concentration on the clearing time of thick emulsion plates.

Plates of 50, 100, 200 and 400 micron thicknesses have been tried. Extra pure quality of Sodium Thio Sulphate was used and the temperatures were controlled in a thermostatically cooling cabinet. Equal sizes of emulsion plates were placed directly without any prior development in equal amounts of hypo solutions. No agitation was given to the solution in the fixing process except that caused by the convection currents produced by slow variation of temperature. The two temperatures employed in this study were $(9 \pm 1)^{\circ}$ and $(15 \pm 1)^{\circ}\text{C}$.

The curves of Figure 2 shows the dependence of clearing time on hypo concentrations for various thicknesses. The clearing time means the time at which the last grain of silver halid gets dissolved i.e. point at which fixing rate is negligible as seen with the eye. Curves A are for temperature $(9 \pm 1)^{\circ}$ and B for

(15 ± 1)°c. The curves of various thicknesses of emulsions have more or less similar shapes, which resembles those given for thin emulsions by Sheppard et al. At lower concentrations the clearing times show a steep fall and again a steep rise at higher concentration. In between these concentration the clearing time is practically constant. Both curves A and B show a similar type of behaviour, but the rise in curve B is not so steep as in curve A. Moreover at a given concentration the clearing time decreases with increase in temperature. This is in accordance with what has been given for thin emulsions.

Although the reasons for this type of variation in clearing time have not been established with certainty, Sheppard et al (1923)¹⁴ put forward that :

$$\frac{dx}{dt} = \frac{k (a-x) D S}{d} \dots\dots\dots(1)$$

where S is the surface area, D is diffusion coefficient, k is a constant of proportionality, d is the diffusion path, a is initial hypo concentration, and x represents the solid (Silver Halide) dissolved in time t. When a becomes too large as compared to x, equation (1) reduces to:

$$\begin{aligned} \frac{dx}{dt} &= \frac{k a D S}{d} \dots\dots\dots(2) \\ &= \text{Constant} \end{aligned}$$

As a increases $\frac{dx}{dt}$ will increase and tends to become constant. This increase in salt concentration will depress the swelling and thereby decreases the diffusion velocity. The balance in two opposing factors brings about the constant region. At still higher concentrations of hypo the reduction in diffusion velocity due to depressing in swelling, is predominant over mass action and clearing time increases.

As seen from the curves, the ~~xxxx~~ region tends to become smaller for thicker emulsions. It is interesting to note that a similar decrease of constant region occurs as the temperature falls. The lowering of the temperature effects the hardening of the emulsion in the same manner as the increase in salt and consequently the depression in diffusion velocity is increased, which disturbs the balance in two opposing factors. This causes the steep rise to begin at lower concentration than would be the case at higher temperature. A similar tentative explanation can be sought for thick emulsions. The thicker emulsions have more gelatin which will effect the balance due to greater depression in swelling in a way similar to that of temperature. It is possible that greater viscous forces may also be playing some part in this decrease of diffusion velocity (as the diffusion coefficient $D = \frac{RT}{N} \frac{1}{6 r \pi \eta}$ where R is constant, T is temperature, N is Avagadro's number, r is the radius of silver halide grain, and η is the viscosity). Due to decrease in diffusion velocity the beginning of the constant region will occur at higher concentrations as the thickness of the emulsion is increased. Other factors, such as agitation, presence of other salts, nature of emulsion etc have their usual effects on the clearing time of thick emulsion plates.

These results indicate that 35% is the optimum value of hypo concentration which should be used for the clearing of emulsion plates of above mentioned thicknesses.

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*** A note on this has been sent for publication to Indian
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C H A P T E R I V .

Methods of track analysis.

Introduction.²

Particle identification constitutes the main item in the analysis of events. Various methods¹⁻³ have been described for this but we are limited only to those which have been used by us in the laboratory.

The particle is completely identified by its mass, energy or momentum, charge and if possible the nature of the charge. These quantities are determined in the emulsion technique with the help of residual range, grain count, multiple coulomb scattering, delta-rays, and taper length etc. The knowledge of two or more of above quantities can tell the requisites of the particle. For identifying the charge and mass of the particle with the help of the relations, the track may be divided into three categories:-

- 1) those due to particles brought to rest in the emulsion. Here charge and mass may be deduced from range ionization, ionization- scattering or range scattering calibrations.
- 2) particles which are in the sub-relativistic regions, i.e. the particles which show slowing but do not end in the emulsion. The ionization scattering method may be applied over successive sections.
- 3) fast particles which show practically constant characteristics along the track. Here also ionization scattering is useful for determining various properties. If, however, the particle is in the relativistic region the charge may be found only by the ionization measurements. In ~~the~~ principle the mass and energy of the particle may be obtained by finding the energy and angle of ejection of knock-on electrons it produces.

The mass value may be determined by comparison with the tracks of recognizable particles such as π or μ mesons or proton

without requiring the knowledge of explicit relation-ship for range ionization or scattering. For heavy particles ionization scattering may provide direct charge ratios. Since μ/z (where μ is the rest mass and z is charge) is constant for all nuclei, the scattering parameter $\bar{\alpha}$ is a function of velocity only. Thus for two tracks showing the same $\bar{\alpha}$, the charge relations in such cases will be give by the square root of the ratios of their ionizations values i.e. delta-ray densities.

Range.

In order to determine the range of the particle two measurements are necessary.³ (1) the projected length of the track on the focal plane of the objective and (2) The angle of dip. The projected length is read either by the eyepiece graticule or by directly measuring displacements on the micrometer heads in the X & Y directions. The stage is moved so that the beginningⁿ and end of the track are in turn brought to a fixed point on the eyepiece scale. Tracks generally show bends due to scattering, therefore the range is measured in small segments. The angle of dip is measured by measuring the vertical component z . Thus if the coordinates of the two points are (x_1, y_1, z_1) and (x_2, y_2, z_2) the ~~length~~ length may be given as:

$$R^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2$$

for brevity if $(x_2 - x_1) = x$; $(y_2 - y_1) = y$; and $(z_2 - z_1) = z$;

we have $R^2 = x^2 + y^2 + z^2$.

For accurate measurements the shrinkage factor is also taken into consideration. The high concentration of silver bromide in nuclear emulsions will result in considerable reduction in their thickness after fixation- when unused silver is removed. The ratio between thicknesses of an emulsion before and after processing is

known as shrinkage factor. One method of its evaluation is the method of direct measurements, where the thickness of the emulsion is measured with the microscope at different points of the whole plate and the ratio of two thicknesses gives the shrinkage factor (S). This technique has been given in detail by Vigneron (1949)⁴. A particularly elegant method of determining the value of S has been devised by Roads (1951)⁵ making use of the optical interference patterns.

The results of these investigations give $S = 2.38 \pm 0.0$ and 2.65 ± 0.07 for Ilford C2 and G5 emulsions, both at normal room humidity. These results are in agreement with those of Rotblat and Tai (1949, 1951)^{6,7}.

Thus the correct range can be given as:-

$$R^2 = x^2 + y^2 + (sz)^2.$$

For a still greater precision the range is also to be corrected for the fluctuations due to straggling³ and humidity.

Range-Energy relations.

When a charged particle passes through matter, it loses the energy in random collisions with the electrons of the stopping material, but the process may be considered continuous when taken over a finite length. If any particle comes to rest after travelling a distance R, it must have spent its initial energy E in the formation of ion pairs whose number may be a function of E. Hence it is to be considered that there is a definite relationship in the energy and range of a given particle in a given stopping material.

Lattes, Fowler and Cuer (1947)⁸ have measured the range of protons upto 13 mev in B₁ emulsions. Bradner et al (1950)⁹ extended the range energy calibrations in C2 emulsions upto 40 mev. The results of measurements and the data supplied by the manufacturers indicate that the stopping power of C2, E1, G5 and NT2a emulsions

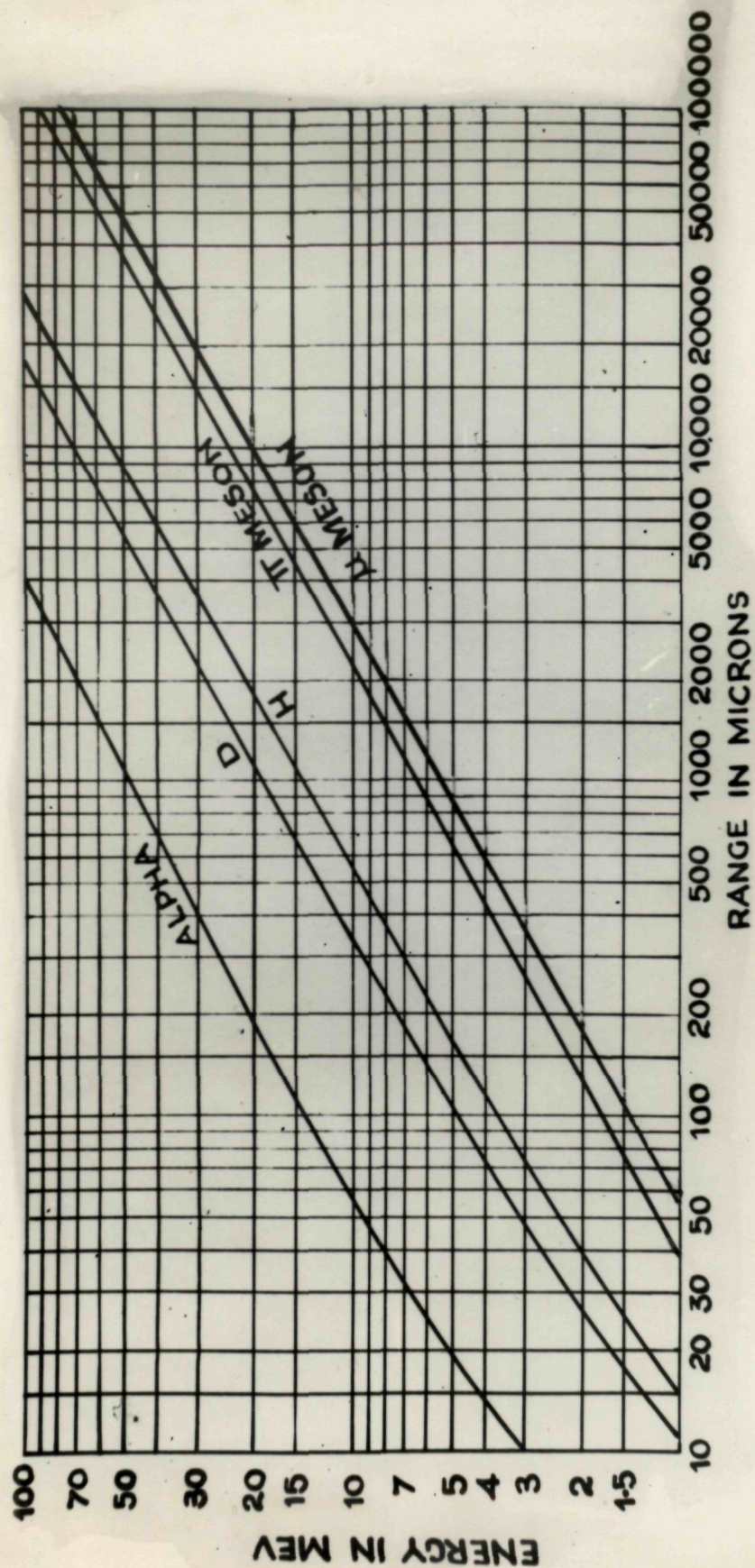


Fig.3. Range - energy curves for G5 emulsions for the range of particles upto 100,000 microns. (Dixit, 1952)

are not much different and therefore there should not be much difference in the range energy relations and curves, but Peck (194) has indicated that small difference in composition and humidity may have large effects on the range energy relationships, but it seems rather likely that his results had a systemic error.

The range energy curves are straight lines when plotted on a double log paper which shows that the relation follows a power law of the type:

$$E = a R^n.$$

which gives the final relation,

$$E = a z^{2n} M^{1-n} R^n \quad \dots\dots (4.1)$$

where M is mass in proton units, E in mev and R in microns. Lattes et al (1948)¹⁸ have given $a = 0.262$ and $n = 0.575$ while Bradner et al⁹ have given $a = 0.251$ and $n = 0.581$. From multiple scattering of cosmic ray tracks in G5 emulsions Gottstein and Mulvey (1951)¹¹ have reported satisfactory agreement with the results of Bradner et al, upto proton energy of 200 mev.

The range energy curves for various particles in C2 emulsions were given by Bradner et al,⁹ but they are applicable to all emulsions manufactured at present. Dixit¹² has extended the range energy curves for various particles upto 100,000 microns range in G5 emulsion. They are shown in figure 3 and are very useful for the purpose. We have used these curves for determining the energies of various particles.

The power law given by the equation (4.1) is accurate within 2% for mean range above 5 mev to 50 mev. The various factors effecting the range will however effect the accuracy of range energy relations.

For sub-relativistic particles i.e. in the region $E/\mu < 0.1$ (where $\beta^2 = 2E/\mu$) the energy loss obeys a power law of the type $\beta^{-1.46}$.

Fowler (1950)¹³ has given that $\frac{dE}{dR} = 0.587 z^2 \beta^{-1.46}$ (4.2')
 kev per micron. The value of dE/dR can be had from his curves and
 thus the velocity of the particle can be directly deduced from the
 relation. This relation has also been applied to near relativistic
 particles ($0.08 < E/\mu < 3$) to deduce the velocity, variation of
 grain density, and the value of scattering constant. Thus to sum up
 the measurement of range R in the emulsion allows a direct determina-
 - tion of mass in proton units by the relation :-

$$4E = M^{0.42} R^{0.58} .$$

Also with the approximation that $M = 2z$ for heavy particles the
 equation (4.1) is reduced to :-

$$3E = z^{1.58} R^{0.58}$$

for the purpose of charge identification.

Grain Counting.

The density of grains in a given track is a measure of
 the energy loss of the particle in the emulsion. But the relation-
 - ship between the energy loss and grain density is not a simple one
 because the phenomena of surface charge and recombination of ions
 will tend to reduce the relative sensitivity of the emulsion at very
 high specific ionization. Demers (1947)¹⁴ and Webb (1948)¹⁶ have given
 the treatment of the rate of grain productions in nuclear emulsions
 Their treatment is based on the theory of Gurney and Mott.
 Considering the effects of space charge etc Blau (1949)¹⁵ suggested that
 effective specific ionization (I) be taken as $(dE/dR)^{\frac{1}{2}}$. The grain
 counting in electron sensitive emulsions provide a measure of the
 velocity of a singly charged particle.

The grain counting is a simple matter if the grains
 are perfectly resolved. This condition is nearly fulfilled by a track
 of low grain density. However, the presence of the background grains,

variation in the size of developed grains, occasional clusters introduce subjective factors in the counting procedure even in the case of thin tracks. On the other hand in the case of heavily ionizing particles the grains are so much clustered and clogged that the resolution is hard to find, that is why when $g \gg 100$ grains per 100 microns direct grain counting is seldom used.

For more objective grain counting the procedure used by us is that with the help of the eyepiece scale we divide the track and count any grouping which is larger than the accepted size of a single (Lattes et al, 1948)¹⁰. Very small or pin point grains are to be left and ignored. Fowler & Perkins (1951)¹⁷ have described the number of grains in a segment of 1 micron length as equal to (2.4×1) grain.

Apart from it the photometric method of grain counting has also been given by Blau et al (1950) which actually counts the blob density.

Lattes et al (1948)¹⁰ were first to use the method of grain counting for the determination of the mass of the particle. This method was extended by Brown et al (1949)¹⁸ and O'Ceallaigh (1951)¹⁹ for 400 micron Kodak NT4 and 400 micron G5 emulsions. The simplest method of analysis by grain counting for determining the mass ratio of two particles ending in the emulsion is to compare ranges at equal ionization density, assuming $g = f_1(\beta) = f_2(R/M)$.

For decreasing the statistical errors, gradually the integrated ionization procedures are adopted that is total number of grains upto a particular range R are counted. This gives $M = M \times F(R/M)$ and the value of the mass can be found if nature of function $F(R/M)$ is known. Lattes et al (1949) have given :-

$$M = K z^{2n'} M^{1-n'} R^{n'} \dots\dots\dots (4.2)$$

They have given $K = 76$ and $n' = 0.711$ for Ilford C2 emulsions. The method gives direct particle mass when applied under good conditions

and performed by experienced observers.

The above method is applicable to slow particles which end in the emulsion, but for grey tracks which do not end in the emulsion, it has been shown that grain density is proportional to dE/dR and velocity depends on $\beta^{-1.46}$. The rest mass in such cases is obtained by the ratio of $p\beta$ and $p\beta/\mu$ derived from its grain density. If g^* is normalised grain density i.e. grain density relative to that for very fast particles the relation $p\beta/\mu = (g^*)^{-4/3}$. This gives satisfactory results in the region $1.5 < g^* < 4$ when direct grain counting is used with G5 plates. For relativistic region the grain density and scattering parameter ($\lambda/100$ microns) is used for the determination of mass.

The method gives the mass value within few percent if the track is about 1 cm long and the conditions of development are quite favourable.

Bradt & Peters (1950)²⁰ and Dainton, Fowler & Kent (1951) have used the method of grain count for the determination of charge both in C2 and G5 emulsions. It has been found that in C2 emulsions I varies as z^2 , but on other conditions it is expected that a relativistic particle of high z and a slow particle of low z will show different grain densities at the same value of dE/dR . The method still needs attention for reaching its final stage.

Multiple Coulomb Scattering.

A charged particle undergoes small deflections in its path when it passes through matter. These are due to elastic collisions with the atomic nuclei in its path and is often termed as multiple coulomb scattering. Bose and Chowdhary (1941)²² were first to suggest the use of scattering for finding the mass and energy of the particle. Later the technique has been applied by Perkins (1947)²³, Lattimore

(1948)²⁴, Goldschmidt-Clermont (1948)²⁵ in Ilford B₁ and C2 plates. Direct measurement of scattering with the microscope eyepiece and graticule, was first given by Fowler (1950)¹³ and Goldschmidt-Clermont (1950)²⁶.

The theory of scattering was put forward by Williams (1939)²⁷, (1940)²⁸ which was extended by Molier (1951). Mathematical results have been given in the convenient form by Scott (1952)⁴¹. According to Williams, the mean deflection suffered by the particle in traversing a path length t in a medium of atomic number z , containing n atoms per unit volume may be given as:-

$$\bar{\phi} = \frac{2 z e^2 (NE)^{1/2}}{P\beta} \times L = \delta \times L \quad \dots\dots\dots (4.3)$$

where δ is convenient unit of angle and L is a logarithmic factor. The results of step wise integration over M collisions, experienced in the path length t yields,

$$L = 0.80 (\log_e M)^{1/2} + 1.45 \quad \text{where } M = (\pi/2) \delta^2 / \phi_{min}.$$

This yields the final form as :

$$P\beta/z = K t^{1/2} / z(t) = K / z_{(100 \text{ microns})} \quad \dots\dots (4.4)$$

where t is the cell length and the other form is obtained by expressing t in units of 100 microns. The scattering constant with normal nuclear emulsions should be given by $K = 10L$.

Two methods have generakly been put forward for the direct measurements of scattering. The first is that given by Goldschmidt-Clermont (1958)²⁵. Here the hair line of an eyepiece graticule is aligned with the track so as to give the best fit with the grains in the field of view. The field is arranged equal to half cell length. Overlapping deflections

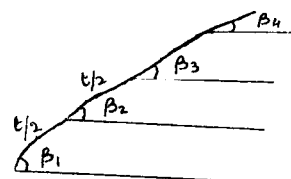


Fig 4 .

between alternate settings are considered (Fig. 4) i.e. $\alpha_1 = \beta_1 - \beta_3$; $\alpha_2 = \beta_2 - \beta_4$ etc from which an arithmetic mean (with cut off) is determined for the track.

The second method has been given by Fowler (1950)¹³ and is often described as 'coordinate' or 'sagitta' method. The method has been given in greater detail by Menon, O'Ceallaigh & Rochat (1951)²⁹. This method gives best result with moveable stages. Here the track is approximately taken parallel to either of the axes and an eyepiece graticule is arranged perpendicular to it. Lateral track coordinates are read at successive intervals along the stage motion (Fig. 5).

Difference of the successive coordinate readings $S_1 = y_1 - y_2$; $S_2 = y_2 - y_3$; etc provides a means for the measurements of angles between successive chords.

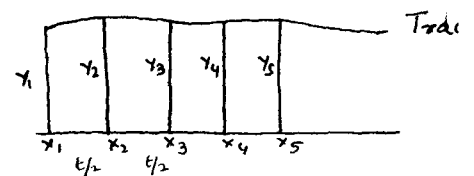


Fig 5.

From these the arithmetic mean \bar{D} is found. The scattering is found by $\bar{\alpha}(t) = (\bar{D} / t) \times 180 / \pi \text{ deg.}$, which can be converted to $\bar{\alpha}(100 \text{ microns}) = \bar{\alpha}_{obs}(100/t)^{\frac{1}{2}}$. Apart from these methods, Mediarmid (1951)³⁰ and Mabbox (1953)³¹ have also given their methods for the determination of scattering parameter.

Biswas, George & Peters (1953)⁴² have given a new method for mass determination, depending on multiple coulomb scattering. In this method the cell length varies in successive measurements so as to compensate for momentum loss and to keep the mean deviation between cells constant for the whole track.

The value of scattering constant used in equation (4.4) has been found by Fowler (1950)¹³, Camerini et al (1950) using the relation $p\beta/z = K / \bar{\alpha}(100 \text{ microns})$ for known particle and have found the value as 32.7 with measurements on grey proton tracks. The value generally remains about 25-26, but Voyvodic and Pickup (1951)² have given the value of $K = 21$.

Generally the scattering parameter is corrected for (a) large angle scattering, and (b) for noise, (c) for track distortion

The large angle scattering has a pronounced effect and in order to avoid it all the measurements which are more than 4 times the average are neglected before taking the arithmetic^{mean} for getting \bar{D} . But sometimes even this cut off is insufficient for a certainty that the effect been toatally neglected. The noise means the apparent fluctuations in track directions which are due to particle's scattering. These may be created due to irregularities in the stage motion errors in reading or setting, and due to the spreading of centres of developed grains about the true particle trajectory. One method to eliminate it is to make scattering measurements on \times two cell lengths s_1 and s_2 and to get \bar{D}_1 and \bar{D}_2 , then true \bar{x} (100 micron) will be given by:-

$$\langle \bar{x}_{100 \text{ microns}} \rangle = \sqrt{100\mu} \times \frac{180}{\pi} + \beta \sqrt{\frac{\bar{D}_1^2 - \bar{D}_2^2}{s_1^2 - s_2^2}} \dots\dots\dots(4.5)$$

where β is one scale division in micron.

Corrections are also made for track distortions which means the curvature introduced in processing. Different types of distortions viz. C-shaped, S-shaped, chopping, etc are introduced in the plates and have been discussed by Bonnetti et al (1951), Dainton et al (1951)⁴⁰ and Fowler (1950)¹³. They have also given the methods for the corrections of such distortions.

The mass determinations of the particles which are ending in the emulsion, is quite easy. From range ~~energy~~ scattering relation we get;

$$4E = M^{0.42} R^{0.58} = z\beta = 2K/\bar{x} \text{ mev} \dots\dots\dots(4.6)$$

and hence the mass can be evaluated. The mass of the particle is expressed here in proton units. This gives the mass as:

$$M = 2K^{3.7} (\bar{x})^{-2.37} (R)^{1.37} \dots\dots\dots(4.7)$$

and the charge as :

$$z = (1.5 K)^{1.73} (\bar{x})^{-1.73} R^{-1.0} \dots\dots\dots(4.8)$$

Menon and Rochat (1951)³² have given a simpler method for mass determination. The mean deflection for 100 micron- $\hat{\alpha}$ - is found for the effective range. The effective range is given by $0.72 R$ where R is the total range. The mass is evaluated by the parameter:

$$P = 1.37 \log R + 2.37 \log \hat{\alpha}.$$

where R is microns and $\hat{\alpha}$ in degrees per 100 microns. Also:

$$P = 7.243 - \log M \quad \text{where } M \text{ is mass in mev.}$$

If the particle is not ending, then the relation $p\beta/\gamma = K/\alpha$ or $\alpha = K\gamma/p\beta$ gives the value of $p\beta$, provided the value of K and α are known.

Errors in this are of the order of 25% if the corrections are not applied. The range scattering method for charge determination has not been used widely and still needs attention.

Gap Length.

For avoiding ununiformity of development and the different types of distortions caused in processing, generally the mean gap length or total gap length methods are used for the identification of the particle's energy and mass etc. The process has been suggested by Fowler and has been given by Friedlander (1954)³³; Here all the gaps above 0.5, 1.0, 2.0, and 4.0 microns are measured with eyepiece graticules. Every gap is observed and classified according to which interval it exceeds. Thus for each segment we may plot on a log-linear paper 5 points which will lie on a straight line. If N_{ϵ_1} is the number of gaps exceeding ϵ_1 and N_{ϵ_2} exceeding ϵ_2 , the mean gap length \bar{G} may be given by the relation :-

$$N_{\epsilon_1}/N_{\epsilon_2} = \exp (-(\epsilon_1 - \epsilon_2) / \bar{G}) \dots\dots\dots (4.9)$$

There is no effect of processed grain diameter. The method has also been given by Hodgson³⁹. He has given the gap density as $(dE/dR)^{-0.7}$ which gives for total gap length :-

$$M_g = b_2 G^{-3.33} R^{4.33}$$

This method gives correct particle mass when it is applied over good conditions. It has been recently used by some workers and still needs improvements.

Delta Rays.

The particle having charge greater than two does not produce any resolved grains even at high energies, The rate of energy loss of such particles is so high that secondary electrons are produced with sufficient energy so as to leave observable tracks in the emulsion. The number of such electrons or δ - rays is a function of dE/dx and with range they provide methods for the determination of charge and energy .

The method was first applied by Frier, Lofgren, Ney & Oppenheimer (1948)³⁴, Bradt & Peters (1948)³⁵. Bradt & Peters (1951, 1952) and Dainton, Fowler & Kent (1951)⁴⁰, (1952)²¹ have advanced the method in Kodak NTB3 and G5 emulsion-s respectively.

Two common procedures for δ - ray counting are based on the establishment of either a minimum length or a minimum grain count criterion. Frier et al (1948)³⁴ ~~xx~~ required that each electron count should have a length of 1.5 microns from the primary track. Bradt and Peters required 4 or more grains in a row. The grain criteria has been used more widely in subsequent experiments. Various curves have been put forward by Zajac and Ross (1949)³⁶, Blum (1951)³⁷. With grain count criteria one may also estimate the minimum energy from a grain density- energy loss calibration in a given batch of emulsion. Sørensen (1951)³⁸ has given detailed account of his procedure of counting . A counting efficiency of 10% on slow alpha particles was estimated by Bradt and Peters (1948)³⁵ and about 70% by Crussard et al (1952)². With ~~xxxx~~ three grain criteria Voyvodic (1950)² reported

maximum δ - ray density about 6.24 per 100 microns for protons and alpha particles at residual range of 500 microns. This is in agreement with Rutherford formula showing a ~~maximum~~ counting efficiency of 100%. This shows that δ - rays allow absolute charge determination.

Following methods are used for identifying the charge of particles; (1) Total number of δ -rays upto range R (2) Comparison of maximum δ -ray density. (3) Range density (4) Scattering density. Crussard and Sørensen have shown that (1) and (2) are applicable to short tracks such as nuclear fragments. If the track length is more than 700 microns, absolute charge determination can be done upto $z = 8$, but due to limited ~~limited~~ δ -ray numbers it is, sometimes, difficult to distinguish close elements like He & Li or Li & Be. For $z > 8$ the clogging of δ -rays and increasing track width makes the charge determination difficult. Methods (3) and (4) have already been discussed before. Hoang (1951) has given the δ - ray density as a power law:

$$N_{\delta} = A_2 z^{1.54} R^{-0.46} \dots\dots\dots (4.10)$$

which corresponds to velocity dependence as $\beta^{1.54}$, for subrelativistic particles. Accurate charge determinations can be made with the comparison of curves given for various known particles.

Taper Length¹

The charge of the particle can be estimated by this method if they happen to end in the emulsion. The track of charge > 2 are quite thick and begin becoming narrower at the end of their range and ultimately stop. This tapering occurs because the initially stripped nuclei capture electrons when their energies become small. This reduces the charge on the nucleus and consequently the rate of energy loss. The tapered length may be used to calculate an approximate value of atomic number z if it is assumed that electron capture

occurs only when its velocity is equal to that of the electrons in K shell, and since the velocities of K shell electrons are proportional to atomic number z , the taper length should also be a function of z . We can write taper length :

$$L = \int_0^z (dx/dz) dz = \int_0^z (dE/dz)^{(dE/dx)} dz \dots\dots\dots(4.11)$$

Frier et al (1948) have given the curves indicating relation in taper length and atomic number. They have given ,
 $L = 0.5 z^2$. Hoang and Morlett (1950) found experimentally that an equation of the form: $L = a z^\alpha$ has a better fit with the data. Here α is of the order of 1. This point still needs clarification.

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Chapter V

Study of Star producing radiation at mountain altitudes

INTRODUCTION

Blau and Wambacher (1937)¹ showed for the first time that if the emulsion plates are left at the mountain altitudes, events showing nuclear disintegrations are observed. These events are named as star. The number of stars increases very rapidly with the altitude and the rate was practically equal to that of the soft component, hence it was thought erroneously that these disintegrations were connected with the soft component of cosmic radiation. Later W.M. Powell (1946)² and Hazen (1944)³ found some examples of the stars in the cloud-chamber working under several cm. of lead plates and showed that stars were not connected with the soft component of cosmic rays. Main results on the stars showed that they were of two kinds. The first type of stars were created by neutral particles other than γ -rays, and the second type equally by Protons and Neutrons. The first type of stars were much more frequent than second type. The low energy interactions were due to Neutrons and high energy ones due to protons and neutrons.

A. Kroff (1948)⁴ summarized the whole data and had shown that (1) the size of the disruptions increases slowly with increasing size of the target nucleus.

(2) The products of disintegration are generally Protons and Neutrons in the energy range of \approx 4-20 Mev.

(3) The events increase rapidly with elevations and the number of Neutrons and Protons is roughly equal in the products. The Protons contribute to total ionization and the Neutrons build up new isotopes at a slow rate.

On the basis of this information the entity producing the disintegrations could be identified. All particles viz. Protons, Neutrons, Mesons, Photons and Electrons can produce nuclear disintegrations. If we consider the cross section for each possible process it will vary with the energy of the particle and the nature of the target nucleus, and it was concluded that Neutrons were mainly responsible for the production of nuclear events. All these stars were termed as Evaporation stars because their formation was first explained by N. Bohr (1937)⁵ on the basis of the evaporation of the nucleus.

General features of the evaporation stars can be explained briefly by the following points (1) Size frequency. This point was investigated by Page (1950)⁶ with C2 emulsions and showed that if the star frequency be plotted against star size on a log-linear paper, the curves seem to follow two absorption processes, one for the low pronged stars (≤ 6 prongs) and other for high pronged stars (> 6 prongs). The two portions may be given by the following equations:-

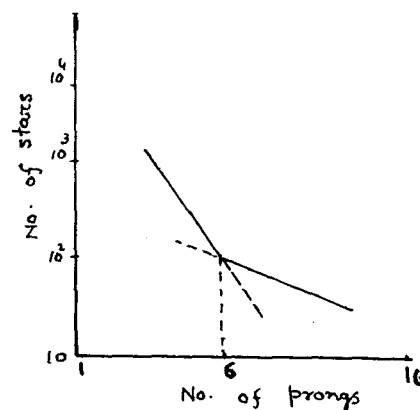


Fig 6.
star freq. vs. star size.

$$N(>n) = A \exp(-0.521 n) \text{ for } n \leq 6.$$

$$N(>n) = 0.38 A \exp(-0.331 n) \text{ for } n > 6$$

This ~~is~~ decrease in the star frequency with increasing star size is an indication of low energy primaries in the atmosphere.

Barton, George and Jason (1951)⁷ have given plot of frequency of occurrence of stars i.e. $N(E) dE$ against logarithm of total energy released in the star. The results fall on a straight line throughout the whole range of stars, and hence, can be explained by a power law of the type;

$$N(E)dE = K dE / E^\gamma \quad \text{with } \gamma = 2.65 \pm 0.1.$$

(2) The type of particles emitted from the stars: This has been done with the emulsions, where energies are found by the range of the particle, when masses of the particles are known. Perkins, Page etc. worked with C2 emulsions. It was found that particles were isotropically distributed and the ratio of the particles with charge $2e$ (alpha particles) to the particles with charge e (protons) seem to be appreciably higher for lighter materials.

An extensive study of the stars was taken up by Brown et al. (1949)⁸ with electron sensitive plates at an altitude of 3,450 meters above sea level. They have classified the tracks according to the grain densities viz. black, grey, and minimum ionization or thin. Gray tracks are mainly due to knock on protons while black tracks were due to evaporation. Fowler (1950)⁹ has confirmed the results of Brown et al. and has shown that gray tracks are mainly due to protons and thin tracks are due to π -meson. Also the black tracks are distributed isotropically while the grey thin tracks have the tendency of collimating downwards. The ratio of grey to black track is 1 : 3 while the average number of evaporation prongs per knock on nucleon is about 1.5. Brown et al. have given an empirical formula for finding the total energy for star size greater than 7 prongs (grey and black) viz.

$$E(\text{Mev}) = 37 N_h + 4N_h^2$$

where N_h are total number of tracks observed with ionization greater than 1.5 times the minimum. Here the allowance is made for the energy carried away by alpha particles and Neutrons.

Many stars show a short thick track which seem to be due to recoil of some heavy nucleus. Hardinge (1949)¹⁰ has made an extensive study and has found that 34% of stars of size 2-5 prongs and 58% of stars of size 6-9 prongs have visible recoil particles. He has deduced the mean momentum transferred to heavy nucleus to be 175 Mev/ on the basis of the mean range while the mean excitation energy is 190 Mev. The mean velocity of the recoil nucleus was estimated to

be 0.01 c while that of the evaporated particles to be about 0.2c. Later Perkins (1949)², Bonnetti and Dilworth (1949)³, Sørensen (1949)⁴ have extended the investigations on heavy nuclei and Perkins has reported that the particles of charge from 2-10, with maximum energy of 300 Mev, can be emitted from the stars.

The study of stars at high altitudes was carried out by many workers viz. Fowler (1950)⁵, Camerini et al. (1949)⁶. Camerini et al. have carried out their experiments with G5 emulsions upto a height of 70,000 ft. and indicated the presence of protons and some smaller numbers of Neutron and Tritons. Rest of the particles are mostly π -mesons with K.E. less than 150 Mev. Some electrons were also present as the product of disintegration. Above this height the stars showed a collimating beam of shower particles, consisting of either π -mesons or protons. These types of stars are usually called 'Jets'.

THEORIES OF STAR FORMATION.

The first successful theory for the formation of stars was put forward by N. Bohr on the basis of nuclear evaporation.²⁰ When a fast nucleon passes through the nucleus this leads to a general heating up or excitation of the nucleus. If the excitation energy of this excited nucleus is less than the Binding energy the nucleus will not explode. It will behave like a fluid in thermal equilibrium. The nucleons will collide with each other in a similar fashion as the molecules of the gas or liquid, and by statistical fluctuation one of the nucleon may get more energy than the average and leave the nucleus. This process will continue till whole of the nucleus comes to normal or stable state.

Bohr suggested that the nuclear processes must be treated as a many body problem because of short ranges of the nuclear forces which requires the particle to interact strongly if they interact at all. The incident particle is captured atleast temporarily, by

target nucleus to form a 'Compound nucleus'. In case of nuclear collision the whole of the incident energy is distributed among all the nuclear particles due to the close coupling. Thus, a compound nucleus formed by such collisions settles to a normal stable state by losing its energy through the emission of material particles (disintegration) or emission of photons (electromagnetic radiation). The particular process is independent of the incident collision. The nuclear reaction can be divided into two stages - firstly formation of a compound nucleus and secondly ejection of particles or particle

Heisenberg in 1937¹⁵ has pointed out that this two stage process is unnecessary and inappropriate. A direct ejection may occur if the emitted particles lie on the surface of the nuclei and if the velocity is distributed outwards. The liquid drop model may also fail for the high excitation energy. Thus, as mentioned by Heitler (1938) that for high excitation energy ($\sim 200-1000$ Mev) it may happen that local evaporation takes place at area where collision occurs before the energy can be transferred to the whole nucleus. The local evaporation taking place before thermal equilibrium is reached and it depends on the heat conductivity of nucleus, a quantity not easily measurable. Heitler has remarked that in the case of low excitation energy (where excitation energy is less than the Binding energy) the equilibrium is attained before any particle escapes.

Weisskopf (1937)¹⁶ has given the probability of the emission of a neutron with energy between E and $E + dE$ is of the form:-

$$P(E) dE = (E/T^2) \exp(-E/T) dE \dots\dots\dots (5.1)$$

where T is the nuclear temperature and T and E both are measured in Mev. The temperature T is related to the excitation energy U by the equation,

$$U = \beta T^n$$

where β is constant involving atomic weight of the nucleus and n depends on the assumed interaction (viz. liquid drop, gas model etc.) For liquid drop model $n = 3$. In the case of charged particles

equation (5.1) may change to :

$$P(E) dE = (E-V)/T^2 \exp. (- (E-V)/T) dE \dots\dots\dots(5.2)$$

where V is the height of the potential barrier. The effect of the barrier is simply to shift the whole energy distribution by an amount V. Perkins (1947)¹⁷ has shown that there are many particles emitted from the nucleus which have much higher energy than given on the basis of evaporation. These high energy particles are undoubtedly protons resulting from the 'knock-on' process given by Heisenberg.

The presence of some very low energy protons and alpha particles may be explained on the basis of barrier penetration first suggested by Gamow to explain the low energy alphas from radioactive elements. But Fujimoto and Yamaguchi (1949)¹⁸ and Lecouteur (1950)¹⁹ have suggested another method. They have suggested that in later stage of cooling the nucleus emits many more neutrons than protons, thus increasing the ~~and~~ ratio of atomic charge to atomic number. The nucleus thus becomes unstable, and loss of positive charge or emission of 'decay protons' become more probable than the emission of positive particle. The life time of this process is found to be between 10^{-15} sec. to 10^{-13} sec. for nucleus of atomic wt. 100 for the emission of protons in the energy range 1.5 - 3.0 Mev.

Equation (5.2) is true for liquid drop where the molecules evaporated from the drop of water is taken analogous to disintegration but the number of particles in the nucleus are so small (100) that actually the nucleus cools down after emission of each particle. Hardinge Lattimore and Perkins have allowed this cooling and they have shown that experimental curves are in a better fit with the gas model ~~is~~ rather than the liquid drop one.

Fermi gas Model.³⁹

This model is also known as Statistical model of the nucleus. Here the nucleus is considered to be made of the gas of protons and neutrons. This model ignores the surface effect like capillarity

which is a serious omission. The volume of the gas is :

$4\pi/3 (1.5 \times 10^{-13})^3 A$ and the particles will occupy the lowest available states. The nucleon gas is completely ~~gaseous~~ degenerate.

The excitation of the nucleus, the extent to which higher states are occupied, may be expressed by attributing a temperature to the gas. This temperature T is often measured on 'dynamic' scale, where Boltzmann's constant $k = 1$ and kT may be written as T . Writing kT for it, the state $T = 0$, corresponds to complete degeneracy. At $T = 0$ the number of states up to highest one occupied are equal to the number of particles with Z or $(A-Z)$ depending whether protons or neutrons are considered.

The emission of a neutron from a nucleus may be considered as an evaporation of the particle from a statistical group of particles held in a potential well. In such excitations generally the energy carried away is kT , which is much less than the total excitation energy of the group of particles. For example suppose a nucleus of $A = 100$ and $Z = 44$ has excitation energy of 20 Mev. The B.E. for neutron is about 8 Mev and the temperature will be about 1.3 Mev. Thus, the neutron will have about 2.6 Mev energy when it escapes. This will still leave about 10 Mev energy which is sufficient to emit another neutron. When the excitation energy goes below the B.E. of neutron, the nucleus may decay by γ - emission.

The protons are to cross the potential barrier also before they can escape from the nucleus and it is of the order of 5-10 Mev. for medium element. Thus, a proton will require $(8 + 5)$ energy for coming out and may come out if the excitation energy is 20 Mev. But the protons are less likely to escape. For elements of small Z , the potential barrier is small and the number of protons emitted are practically ~~more~~ equal to the number of neutrons, but for large Z the neutron emission dominates. When the excitation energy is much larger as in the case of cosmic ray phenomena the alphas or even the heavier fragments may be emitted from the nucleus.

ABSORPTION MEAN FREE PATH(or attenuation length)²⁰

It is defined by the average thickness which will reduce the intensity of N - rays by a factor of $2/e$. Thus if I_0 is the intensity at any point A and I at the point B, which is x gm/cm² below A then the relation between I and I_0 is given by :

$$I = I_0 \exp (-x/\lambda_A) \dots\dots\dots (5.3)$$

where λ_A is known as absorption coefficient.

Absorption of star producing radiation in atmosphere has been widely studied by Camerini et al (1949)¹⁹; Lord and Schien (1950)²¹. Both have used the G5 emulsions and have extended their studies upto 70,000 and 95,000 ft. (15 gm/cm² residual atmosphere). The results indicate a great increase in star rate with altitude and also a striking change in the distribution of particles from the stars. There is a marked increase in the number of high energy events at higher altitudes. Lord and Schien have found that at 95,000 ft. 90% of the stars are created by the charged particles but at 11,000 (Brown et al)⁸ practically equal numbers are created by protons and neutrons.

The absorption length of star producing radiation was also measured at mountain altitudes by Bernardini, Cortini and Manfredini (1949)²² Bridge, Hazen, Rossi and Williams (1948)²⁴. Bernardini et al²³ have found the value of $\lambda_{air} = 135 \pm 4$ gm/cm² upto 20,000 ft. using G2 emulsions. George and Jason have also used similar plates and have found $\lambda_{air} = 150 \pm 7$ gm/cm² upto the height of 3,457 meters. Bridge et al used cloud chamber for these studies and got the value of the absorption length about 138 gm. cm.⁻²

It has also been shown that there is no marked change in the distribution of the size of stars upto 20,000 ft. from sea level. This goes to indicate that N rays (star producing radiation) are practically in the state of equilibrium in the lower altitudes. Frier, Ney and Oppenheimer (1949)²⁵ have studied star size frequency

and have found that there is a marked decrease in the low pronged (3-5 prongs) stars as we go to the top of the atmosphere. 6 or more pronged stars practically remain constant. Camerini et al (1949)¹¹ have shown that these small stars are due to evaporation process and are excited by a process which is of secondary origin.

The absorption length in condensed matter has also been studied by Bernard et al. They have shown that the star producing radiation showed a transition effect in lead and the maxima was indicated at 2 cm thickness. Malaspina has shown that the maxima can also be had even if the absorbing material is kept at the bottom of the plates. This goes to prove that the maxima is closely correlated to N-rays, and the N-rays are completely isotropically distributed in the absorber. The absorption length in lead has been given to be $(430 \pm 90) \text{ gm/cm}^2$. Other absorbing materials could not exhibit a similar transition effect.

The latitude effect of star producing radiation was measured by Yagoda (1949)²⁶; Salant (1949)²⁷; Simpson (1949); Lattimore (1949)²⁸ and Dixit (1950)²⁹. Yagoda has given that 6267 ft. the rate of stars falls by a factor of 2.6 between geomagnetic lat. of 55°N and 39°N . All workers have found a decrease in the latitude effect with increasing star size. Lattimore has shown the star rate at Jungfrau joch and Andes at 11,500 ft. using G5 emulsions. His results indicate an overall increase of (2.1 ± 0.4) stars per c.c. per day as we go from Andes to Jungfrau joch.

The decrease in latitude effect for large stars is similar to penetrating showers and has been explained on the same basis. Smaller stars are generally produced by nucleons which are progeny of Primary Cosmic ray particles and have energy lower than the cut off value corresponding to the particular geomag. Latitude, where the observation are made. Lattimore has shown that data requires at least half of the stars which have been produced by primary cosmic ray nucleons while the other half by secondary nucleons. The ratio of particles in the two

groups is about 1 : 50, any effect exhibited by the primaries will be much pronounced in the secondaries.

STATEMENT OF PROBLEMS.

In view of the above information the study of stars on the following points was undertaken in this laboratory by the author:-

- (2) The study of absorption length of Star producing radiation using electron sensitive plates at an altitude of 13,500 ft. with a view to confirm some of the previous results.
- (2) To calculate the Latitude effect of star producing radiation and to evaluate the star ration
- (3) To find out the directional effects of cosmic ray phenomena viz.
 - (a) directional effects of singles recorded in electron sensitive plates with a view of finding the assymetries.
 - (b) directional effects of stars - if any.

EXPERIMENTAL DETAILS AND RESULTS.

The Gulmarg Research Observatory provided us the advantage of carrying out this study. The Observatory is situated at 9,000 ft above sea level at a Geomagnetic Latitude of $24^{\circ} 36'$. This heights of 13,000 and more are easily approachable from there. All the plates were exposed in the close vicinity of this Observatory.

Different batches of 200 microns thick G5 emulsion plates were exposed without absorber at different altitudes. One batch was exposed for 7 days at an altitude of 13,500 ft. and other at 9,000. Another batch of similar plates was exposed for about 48 days under 6 cm. of lead absorber at 9,000 ft. All these plates were placed in the vertical direction in a light wooden box. The boxes were similar in all cases and were placed on the horizontal plane so that the direction of plates was not at all disturbed. At the altitude of 13,500 ft. similar plates were placed in another box, arranged at

30° and 60° on either side of the vertical direction. This box was also made up of light wood and the plates were placed without any absorber. Emulsion surface of the plates placed at different zenith angle on either side of the vertical, was facing ~~top~~ upwards. The whole box was placed in the magnetic east-west direction with the result that the plates were directed towards 30° and 60° east and west.

All these plates were developed by the temperature cycle method using Amidol developer. As already remarked in Chapter III, we soaked all the plates in cold water prior to development and all the operations were performed at low temperatures.

These plates were scanned only for cosmic ray stars. The criteria which has been accepted for this requisite is that ~~the~~ it must have at least one prong equal to or greater than 100 microns and that the star must have 3 or more visible prongs. Some workers viz. Dixit (1952)³⁰ have used the criteria of 60 microns for the length of the track, but to be on a much safer side we extended it to 100 microns. Table VIII summarises the data of plates placed vertical stars per c.c. per day has been finally evaluated here.

TABLE VII
Star frequency in plates placed vertical at different altitudes.

Altitude	13,500 ft. without Absorber.	9,000 ft. without absorber	9,000 ft. with 6 cm. of lead
Total No. of stars	112 ± 10	44 ± 5	251 ± 30
Total Vol. of the emulsion scanned	0.75 c.c.	0.75 c.c.	0.84 c.c.
Total No. of days exposed	7	7.5	48
Stars per c.c. per day	21.5 ± 1.8	7.8 ± 1.0	6.25 ± 0.75

From this an estimate of the absorption length of star producing radiation can be made. As shown by the equation (5.3) we have

$$I = I_0 \exp (-x/\lambda_A).$$

The value of x between 13,500 ft. and 9,000 ft. will be about 132 gm./cm² and this gives the absorption length of as:-

$\lambda_{\text{air}} = 130.6 \pm 5.0 \text{ gm./cm}^2$ Similarly the absorption length of star producing radiation in Lead λ can be found by the use of a similar equation and taking the value of $x = 70.0 \text{ gm./cm}^2$ the results give:

$$\lambda_{\text{lead}} = 310.0 \pm 12.6.$$

These values of ~~absorp~~ absorption length are in close agreement with the values obtained by Lattes, Occhialini and Powell (1947)³¹; Perkins (1947)¹⁷; and George and Jason (1949)³². The value of absorption length is also in agreement with the absorption length of Neutrons, which goes to confirm that at mountain altitude Neutrons constitute a considerable factor of N-radiation, Simpson (1953)³³ has reported a variation in absorption length of Neutrons between the equator and 55°N latitude. He has shown a change from 228 gm/cm². to about 128 gm/cm² at ~~xxxx~~ the height of 300 gm/cm². ^{atmosphere} ~~atmosphere~~, But no similar change was observed in absorption length below 600 gm/cm² atmosphere. In view of the above information we have also measured the absorption length at 13,500 ft. altitude, which corresponds to 612 gm/cm² atmosphere. The results given by Bernardini et al (1949)²³ show an absorption length for air as $135 \pm 4 \text{ gm/cm}^2$. The experiments were conducted at Testa Grigia which is at a geomagnetic Latitude of 56° 42'N. These results are in a perfect agreement with our results, indicating thereby that the variation of latitude does not change the absorption length of Star producing Radiation, upto 612 gm/cm² atmosphere at least.

The results reported here are in close agreement with the values of absorption of N-radiation ($\sim 128 \text{ gm/cm}^2$) given by Curtis⁵ and Gill (1952)³⁴ at the same elevation and at the same place.

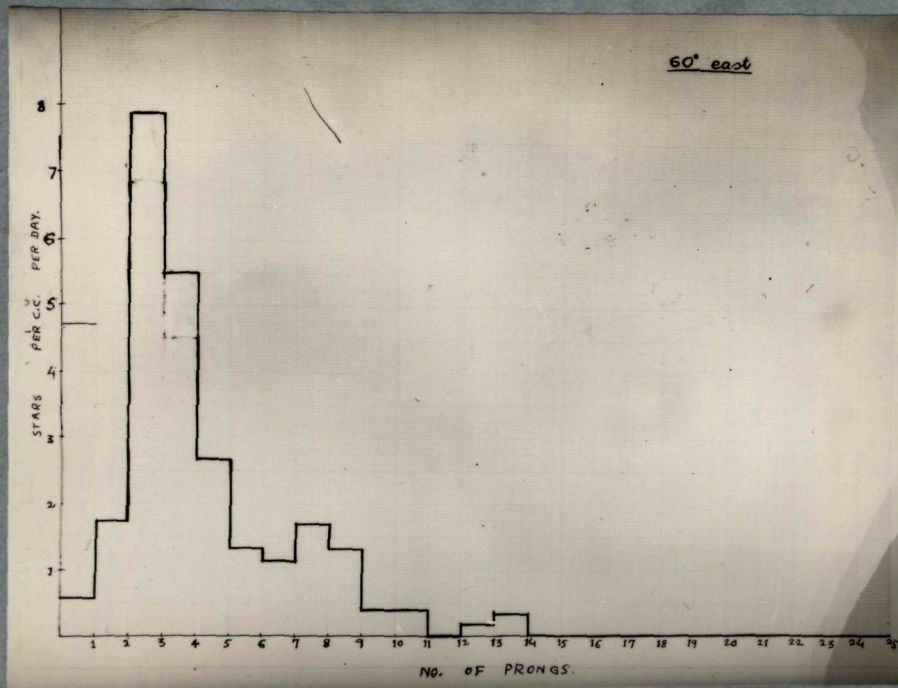


Fig. 7. Histogram representing the star frequency with star size in plate placed at a zenithal angle of 60° east in the eastern direction.

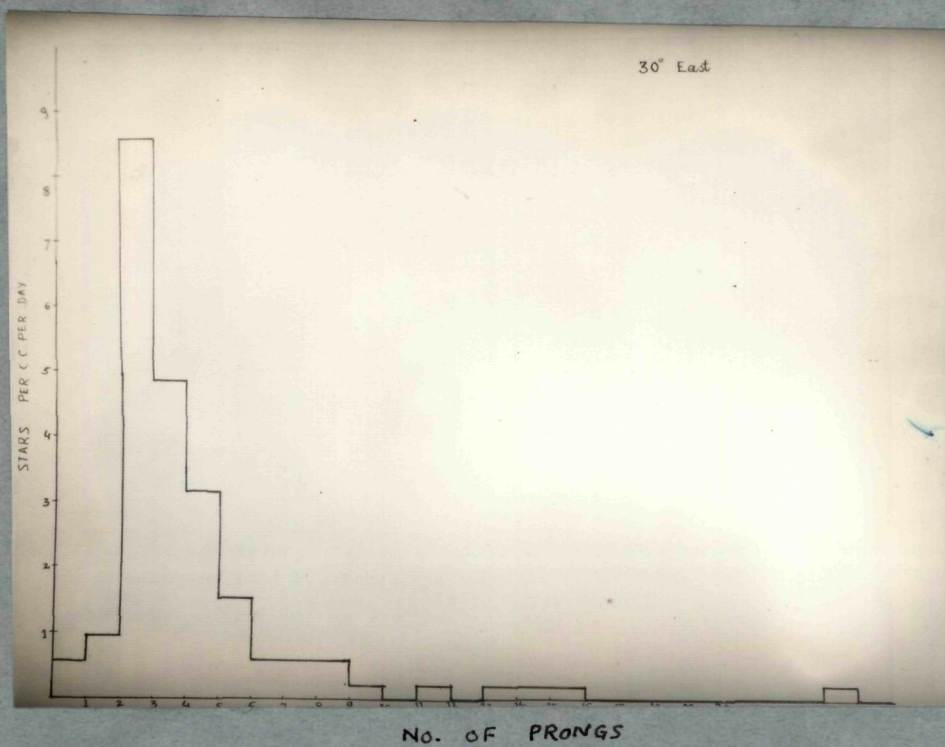


Fig. 8. The plot of stars per c.c. per day with star size for the plate (G5, 200 micron thick) placed at 30° zenith angle in the eastern direction.

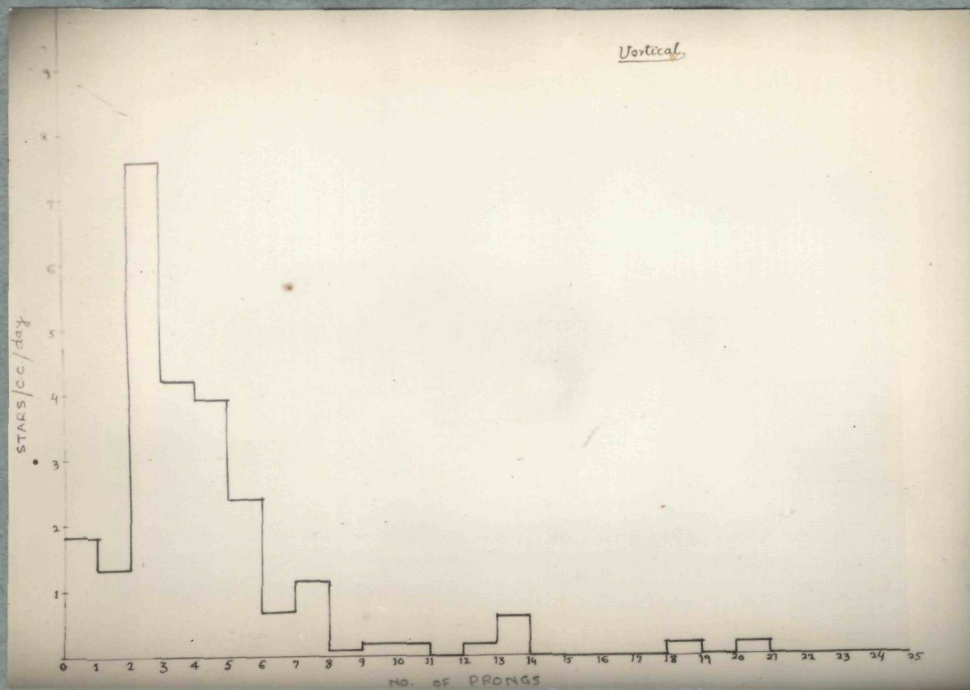


Fig. 9. Histogram showing the star frequency against the star size for G5, 200 micron thick plates placed vertical.

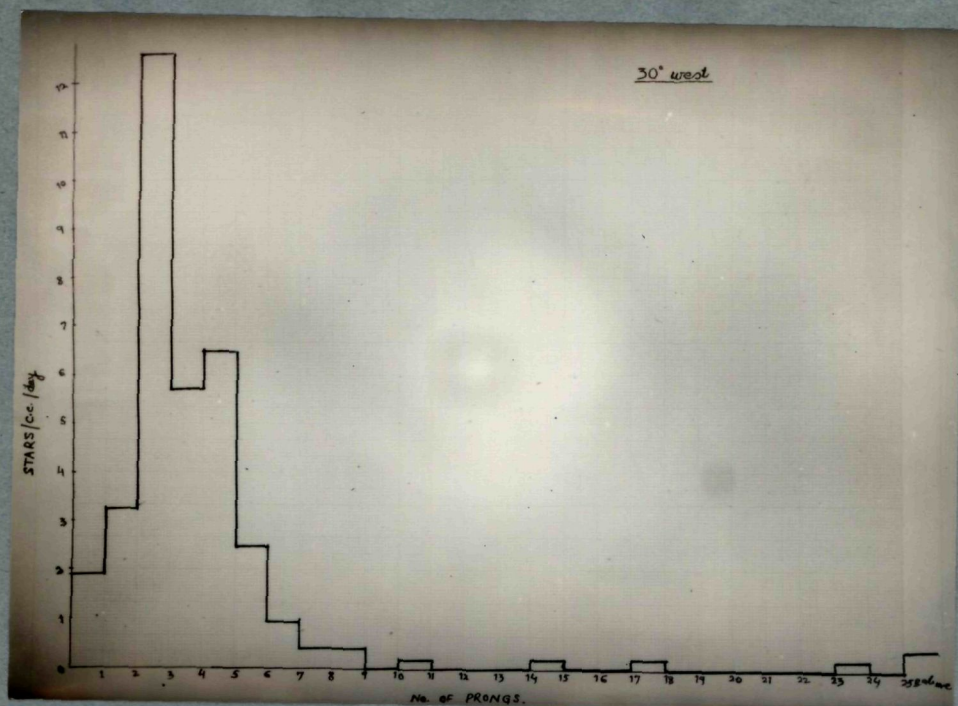


Fig. 10. Variation of the no. of stars per c.c. per day with no. prongs of the star observed in G5, 200 micron thick plates exposed at 13,500 ft without absorber. The plates were oriented in the west at a zenith angle of 30° .

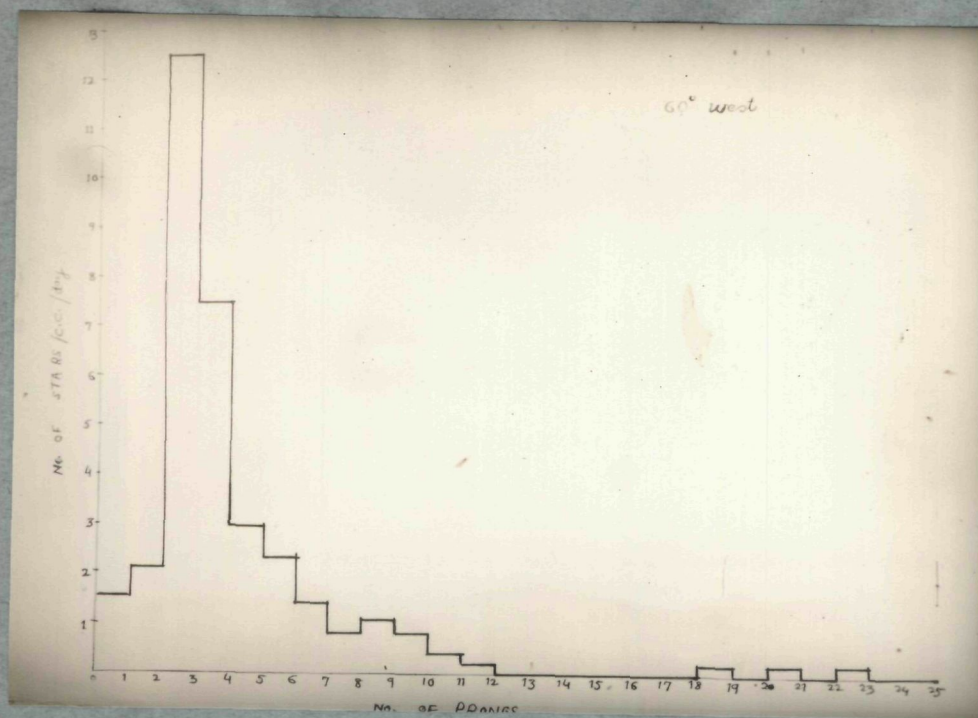


Fig. 11. Histogram showing star rate against the star frequency for G5, 200 micron thick plates placed in the western direction at 60° west.

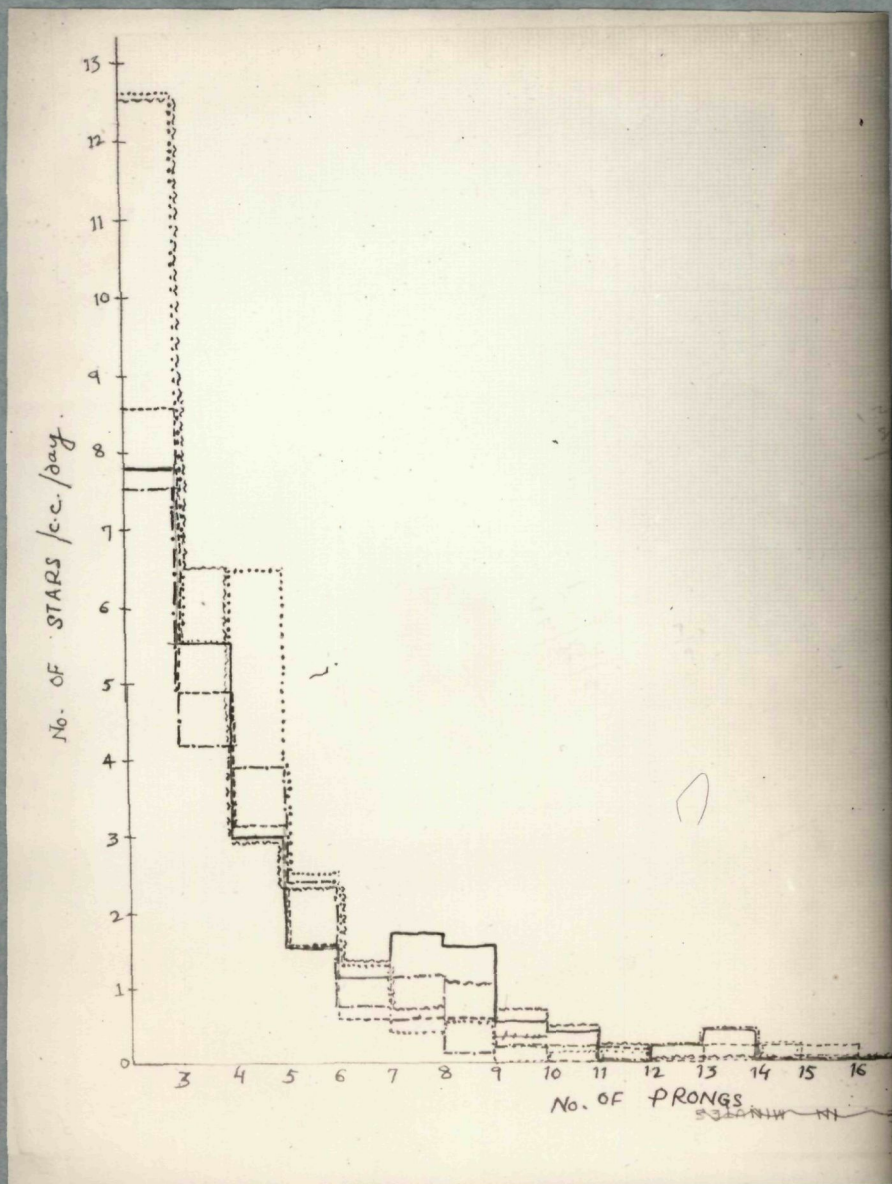


Fig. 12. Comparison of star size vs. star frequency at zenith angles of 30° and 60° on either side of a vertical in the eastern and western directions.

——— 60° east
 - - - 30° east
 . . . vertical
 . . . 30° west
 . . . 60° west

LATITUDE EFFECT OF STAR PRODUCING RADIATION..

The latitude effect of star producing radiation has been reported by many workers . We have also estimated the latitude effect in the radiation between geomagnetic latitude of 24°N (Gulmarg Research Observatory) and 56°N (Testa grigia). Bernardini et al²³ have given the star flux at 56°N as 15.3 ± 0.7 stars per c.c. per day. These experiments were performed at 3,500 meters (about 11,000 ft.) without any absorber. This data, if corrected for height, would give an estimate of the flux at 9,000 ft. in the same latitude as :

$$\begin{aligned} I &= (15.3) \exp(-60/135) \\ &= 9.5 \text{ stars per c.c. per day} \end{aligned}$$

The above results (Table 7) give the value of star frequency at 9,000 ft. at 24°N . This gives the Latitude effect of 1918% between 24°N and 56°N geomagnetic latitude.

DIRECTIONAL EFFECTS

STARS

The plates exposed at 13,500 ft. at Zenithal angles of 30° and 60° in the east west direction have also been analysed for cosmic ray stars. The criteria was similar to that stated above. The results have been summarised in Table 8, where the stars per c.c. per day of different visible prongs have been given for different directions. Fig. 12, 13, 14, 15, 16 give the size distribution of stars for 30° east, vertical, 30° West and 60° west respectively. Fig. 17 gives a comparison of all histograms showing the differences in these distributions.

A Paper 'Star Producing Radiation at Mountain Altitudes' has been presented by the Author at Symposium of High Altitude Sciences at Gulmarg - May, 1955.

TABLE VIII

Distribution of stars per c.c. per day at different zenith angles

Prongs	3	4	5	6	7	8	9	10	Total
30° East	7.57+0.95	4.853+0.095	3.245+ 0.095	1.52	0.573	0.572	0.572		20.953+1.25
60° East	7.80+0.40	5.33+0.20	2.96+ 0.29	1.52+ 0.19	1.14	1.65+ 0.05	1.46+ 0.13		22.20+1.40
Vertical	7.53+1.62	4.20+0.19	3.91+ 0.098	2.35+ 0.20	0.675+ 0.275	1.14	0.095+ 0.095		21.50+1.80
30° West	12.60	5.50+0.20	6.70+ 0.30	2.50	1.30+ 0.40	0.40	0.49+ 0.090		28.40+0.40
60° West	12.50+0.50	6.65+0.53	2.95+ 0.01	2.28+ 0.18	1.33	0.761	1.03+ 0.11		29.4+ 1.80

The general nature of the size distribution as indicated by these histograms is more or less similar to each other and these agree with the results given by other investigators. All these histograms exhibit maximum frequency for 3 pronged stars and the number of star per c.c. per day decrease as size increases. Fig. 18 shows the comparison on a log-linear paper which exhibit the same property in another fashion. The general shape of the curves Fig. 18 is in agreement with the curves given by Perkins (1949)¹² and Page (19). All these indicate that in the case of low pronged stars (≤ 5 pronged stars) there is a marked difference in the number of stars from different directions. The number of stars per c.c. per day at 30° east and 60° east and vertical fall close to each other within statistical fluctuations. Similarly, the number of stars from 30° west and 60° west have about the same values. But the number of stars from western azimuth, however, is much higher than from the eastern horizon. If the number of stars from western direction and from eastern direction are compared, it is found that the difference is much larger than that ascribed to statistical fluctuations. This shows a pronounced east west affect. The values of these asymmetries have been summarised in Table 9. The values have been calculated by the usual methods of computing the east west asymmetries viz.

$\frac{N_w - N_e}{\frac{1}{2}(N_w + N_e)}$ where N_w and N_e indicate the number of stars per c.c. per day, from western and eastern directions respectively.

These plates were manufactured and transported in a single batch and exposed simultaneously for equal interval. All the plates were processed together after exposure. Even the scanning of the plates was done very slowly in equal times at the total magnification of 300 (objective x 20, eyepiece 10 x, and microscope magnification 1.5). We, therefore, believe that this difference in number of stars cannot be attributed to the difference in the rate of scanning as

T A B L E IX

(Percentage difference of low pronged stars)

Prongs	3	4	5
30° east & 30° west	38.1 \pm 1.3	12.5 \pm 2.1	----
60° east & 60° west	42.3 \pm 3.0	32.0 \pm 4.2	-----

given by Cortini and Manfredini (1949)⁴⁰. These workers have shown that the probabilities of missing the events increases very much if the rate of scanning is slightly increased and this effect is most marked for low pronged stars. The high prong stars are practically unaffected by this loss.

Dixit (1952)³⁰ has given the difference in the number of stars observed in the plates exposed in vertical, inclined and horizontal directions. He explains ~~him~~ that if a cascade is assumed for the formation of stars, few stars are likely to be missed when the plates are horizontal than when they are inclined or vertical. Percentage difference in the number of stars given by him the ⁱⁿ inclined and vertical is about 5.7% and vertical and horizontal is about 32%.

In light of the above we should expect increase in the number of stars on either side of the vertical and this increase should be equal on both sides within statistical limits. But data in Table 8 (for 3 pronged stars) indicates that percentage increase from vertical to 60° zenith angles is 12.9% in the east direction and 50% in the case of plates placed in the direction of west. Comparing these results with those of Dixit (1952) the difference in the number of

stars from vertical to those from eastern azimuth is within the limit put by Dixit but the difference in Western direction is much larger than that given by him, even if considerations for statistic fluctuations are made. In view of the fact ~~that~~ the box was placed at the top of the mountain where the incoming radiation was unobstructed the difference exhibited by the stars from two direction must be associated with some difference in the nature of radiation producing these stars. The number of stars studied are only 1,000 in all and therefore, no definite arguments can be advanced about the nature of assumed differences. However, there is no doubt that the difference exists. It is known that the stars are produced mainly by nucleonic component (N-radiation) of cosmic radiation. This radiation is known to be isotropic in the atmosphere. If these stars are mainly created by the N-radiation it would be difficult to explain the assumed east-west difference, because the star producing radiation is coming from all directions and the emulsion plates, which are a continuously sensitive medium, will register all the disintegrations. Moreover, the theory of formation of stars is unable to attach any definiteness in defining the direction of incoming radiation and consequently does not give any support in explaining these differences. However, considering the cascade production of stars, a directional effect can find some explanation. When a plate is placed vertical, vertically incident radiation will have greater length of emulsion ^{to} ~~of~~ pass through and the probability of creating stars will be greater by cascade process than the radiation coming from any other direction. Thus, in the case of plates, placed at different zenith angles the probability of creation of stars is more for the radiation coming in the narrow cone along the angle rather than for the radiation coming from other sides. If

be true the probability of the creation of stars in plates with plane oriented along the western direction is more than those from the eastern directions. The observed difference in the number of stars may be due to some sort of difference in the nature of N-radiation in the two directions. No reliability can be laid on this tentative explanation at present without finding out the stars created by the radiations from a given direction. More data is needed for examining this question.

SINGLES

The plates oriented at different angles have also been examined for single tracks. ~~These~~ single tracks from plates oriented at different zenith angles were examined. ~~by~~ Tsei chu and M. Morand (1953) measured the angles that each track makes with the vertical for possible directional effects. They measured all the tracks which are longer than 300 microns and have shown that an asymmetry exists for all the tracks excluding those of very low energy. Eliminating the particles of energy less than 21 Mev., they found an asymmetry at 0.32 ± 0.09 at Tamanresset.

We exposed the plates at 13,500 ft. above sea level at the Geomagnetic latitude of 24° N. In scanning the criteria for the single tracks was taken that it should lie within 10° on both sides of the horizontal line and it should lie within 10° with the horizontal surface of the plates. All the singles thus counted were divided in three groups (a) all those which were less than 100 microns (b) all those which were between 100-1000 microns, (c) all those which were more than 1000 microns. The above criteria allowed the measurements of tracks only in a small solid angle in a particular direction. The solid angle thus formed has a lateral dispersion of

20° and the angle of the cone will also be 20° . The observations were made at the total magnification of 300 x and at the same rate. The tracks less than 100 microns were all due to radioactive contaminations. Some very small thick fragments of nuclei were also less than 100 microns but the total number of such tracks was very small in the whole plate. The east-west asymmetry could not be calculated for these tracks.

The tracks between 100-1000 microns could be those which were due to slow particles and which stopped in the emulsion. Both proton and meson tracks were found in this category. In this range were also those tracks, which were at black ionization and passed through. ~~These~~ Thirdly, the tracks at grey ionization which entered the emulsion and went out of it. This group included some tracks of particles emitted from the stars. On the whole, this group contains slow particles and were mostly protons.

The third group of tracks having their lengths greater than 1000 microns were mostly due to particles of high energies moving at relativistic velocities. The tracks were mainly grey or thin (minimum ionization). The grain densities also did not exhibit any marked change along their paths. The tracks were mainly due to high energy particles, which passed through the emulsions. For asymmetry measurements this group was considered.

These tracks may be due to particles entering the plate from any direction and getting scattered at their entry in the plate. (The possibility of large angle scattering becomes more due to the presence of heavy nuclei in the emulsion). They could be due to recoil particles - the neutrons coming from any direction causes a proton to recoil and they may leave such tracks. The high energy charged particles coming in the narrow cone in particular direction will also leave such tracks. The tracks of length greater

than 1000 microns are mainly due to the last mentioned cause, because the probability of large angle scattering and inter-action is very small, for these tracks, due to their high energies.

The data indicated in Table 10 can be used to calculate the assymetry of cosmic ray particles in two directions. As mentioned above, only the tracks of ranges more than 1000 microns have been used for calculating this assymetry. The assymetries have been calculated by the usual methods of computing viz. $\frac{(NW - Ne) \times 100}{\frac{1}{2} (NW + Ne)}$ where NW and Ne represent the tracks from western and eastern directions respectively.

TABLE X

Single tracks observed in the narrow cone of 20° classified according to their ranges in the emulsion.

Directions	Tracks 100 microns	100-1000 microns	>1000 mic.	Total area scanned.
60° East	—	130 ± 15	101 ± 9	37.5 sq. cm.
60° West	27 ± 3	141 ± 12	145 ± 10	37.5 " "
30° East	6	50 ± 2	110 ± 5	12.5 " "
30° West	—	—	—	—

The data show an assymetry of 37.5% at 60° zenith angle. The value is higher than that given by Tsai Chu and Morand. But the difference may be explained on the basis of latitude and altitude of the two places of observations.

The values may also be used for calculating the value of exponent of the intensity distribution law. It has been given that intensity I at any zenith angle about the vertical can be given by the equation - $I = I_0 \cos^\lambda \alpha$.

where I_0 is the intensity in the vertical direction and λ is a constant



This will give -

$$I_{60} = I_0 \cos^{\lambda} 60 \quad \text{while} \quad I_{30} = I_0 \cos^{\lambda} 30$$

Substituting the values from table 10 we have:-

$$2.4 = (1.4)^{\lambda} \quad \text{or} \quad \lambda = 2.6$$

The value of exponent lies close to the value of (2.56 ± 0.28) given by M. Morand and Tsai Chu (1952)³⁷. The above results of assymetry and exponent are closely comparable with the results of assymetry in the exponent given by Gill and Khara (1955)³⁸ for total radiation. These workers have studied the east-west assymetry ~~at~~ at the Gulmarg Research Observatory with G.M. Counters at an altitude of 9000 ft.

In the course of study of these effects we have also come across some interesting cosmic ray stars. A few of them are given below as examples. The exact identification of the disintegrating nucleus was difficult in some cases because the recoil nucleus left very small track of the order of 5 microns or a heavy blob. The excitation energy has been calculated on the basis of method given by Brown et al. (1949)⁸. The particles coming out of the nucleus are identified and their kinetic energies are calculated. Then kinetic energy of neutrons which leave the emulsion un-noticed is added up (equal to 1.25 times the total energy of protons). This gives total kinetic energy of disintegration. The estimate of the disintegrating nucleus gives the Q values of the reaction.

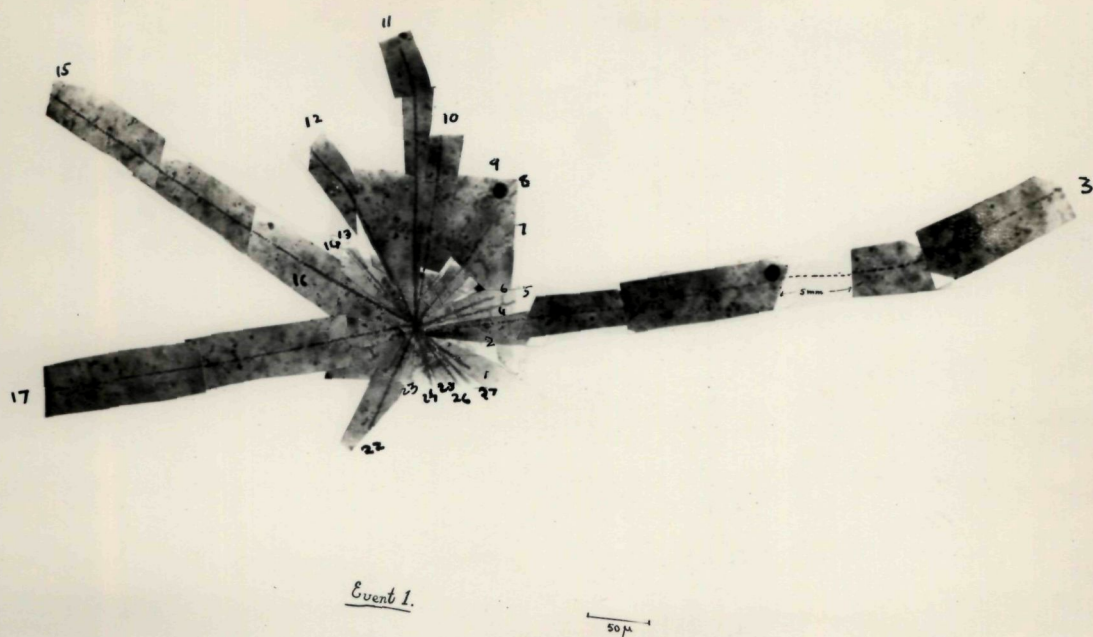


Fig. 13. Complete evaporation of a heavy nucleus by a neutral particle. The photomicrograph has been taken at 95x. The event has been observed in G5 emulsions, 200 micron thick.

E V E N T 1

This event is shown in Fig. 19. It is a 27-28 pronged star. All the tracks of this star are going out of the emulsion except track number 10, 11, 18. A correct mass identification was possible only in these cases. Track 10 was due to a proton, while ~~ix~~ 11 was that of a Deuteron. The range of this particle was 100 microns. Track 18 is due to an Alpha particle, with ~~range~~ range about 285 microns.

Track 3 was a long track ~~at~~ at minimum ionization going out after several thousand microns. It has suffered a Rutherford scattering, which is rather uncommon at such high energies.

The other tracks are of all types viz. black, grey, thin and heavy recoil nucleus. The grain densities of some of the thin tracks clearly indicate them to be due to mesons. A correct estimate of the disintegrating nucleus could not be made as all the tracks ~~were~~ could not be identified, but it is almost certain that it is a disintegration of heavy nucleus (Ag or Br or I). All the tracks are isotropically distributed.

This star is an evaporation star, where a heavy nucleus has been evaporated by a neutral particle.

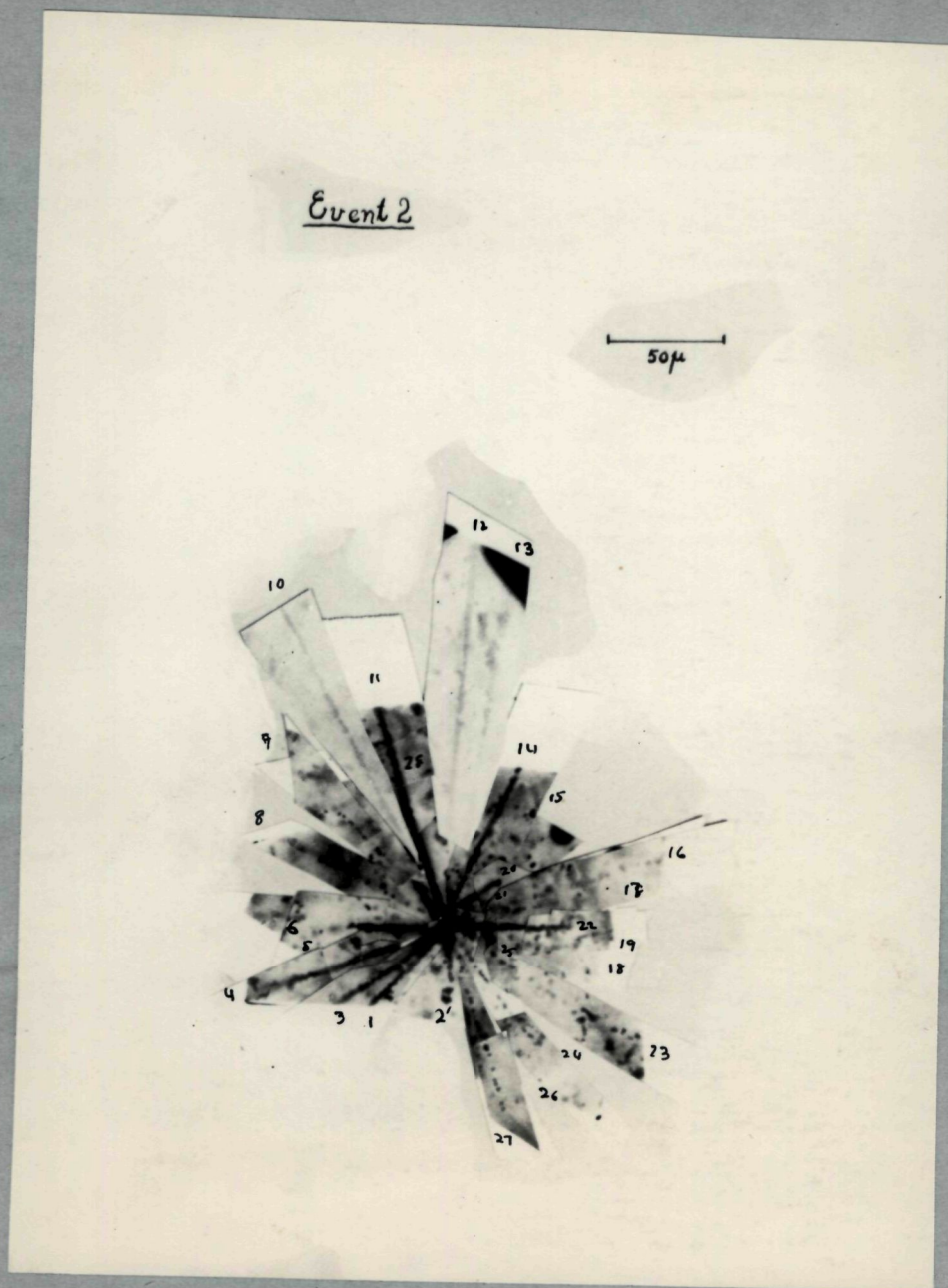


Fig. 14. Photomicrograph of a star representing the disintegration of a heavy nucleus by a neutral particle. A proton shower has come out in the disintegration.

E V E N T 2

This event is shown in Fig 14. . This is also a 28 pronged star. It shows so many high energy particles going out of the emulsion at min. ionization. All these particles are collimated in a small cone and clearly shows that they are due to shower particles. The shower constitutes the high energy protons and mesons going out of the emulsion.

Rest of the tracks are due to evaporation.

This is a disintegration of a heavy nucleus, out of which a shower has come out.

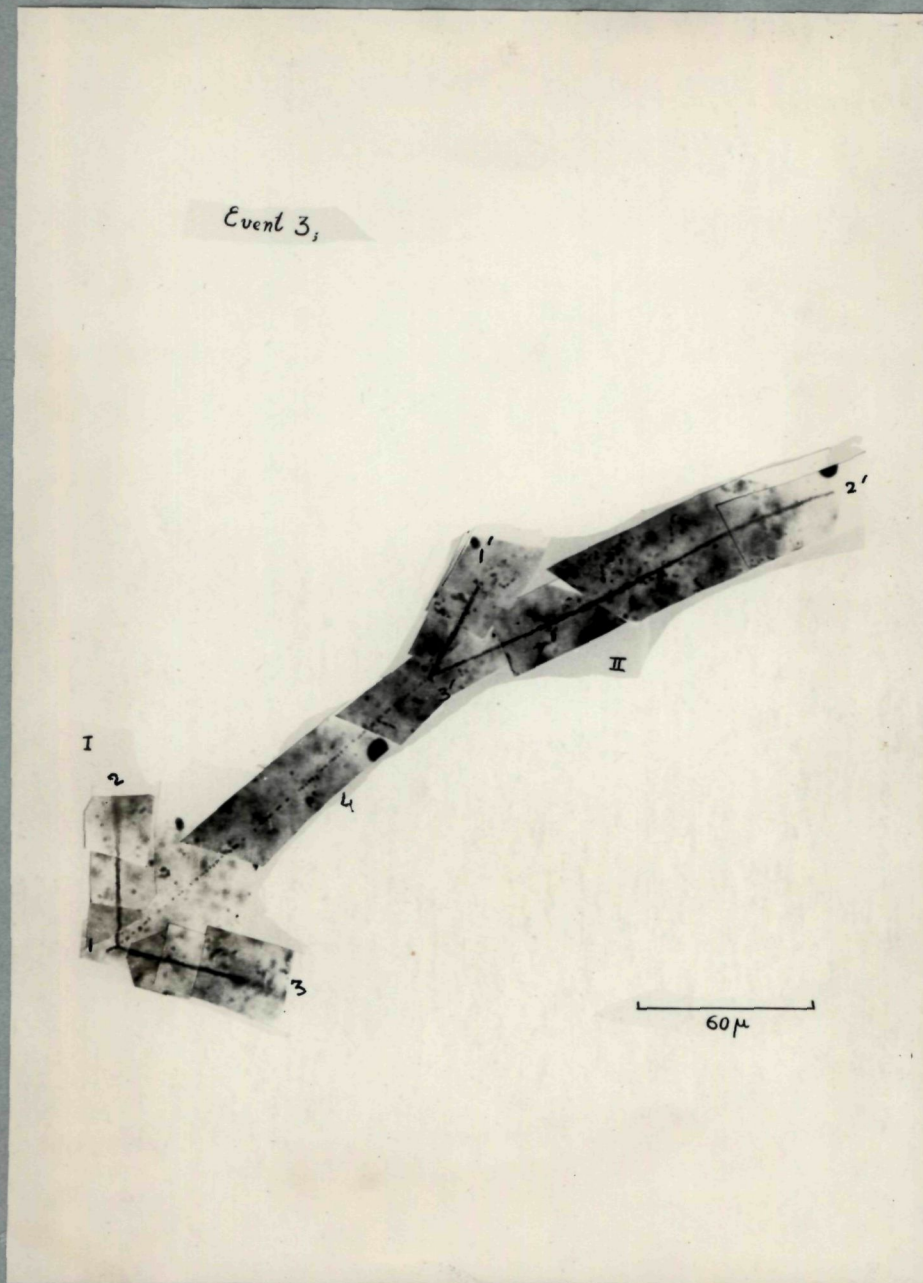


Fig. 15. Photomicrograph (95x) of a double star which are connected by a track at minimum ionization. The event has been observed at 13,500 ft in 200 micron thick G5 plate.

E V E N T 3

Event 3 is shown in Fig. 15. This is an example of a double star. Two small stars I and II are connected by a track at minimum ionization. Description of these stars is as follows:-

Star I. It is a three pronged star leaving aside the track connecting the two stars. Track 1 is a small track of four or five microns long ending in the emulsion. Tracks 2 and 3 are thick tracks going out of the emulsion after 100 and 300 microns respectively. Both of them appear to be evaporation tracks of protons. There is a doubt that track 3 may even be due to Deuteron.

Star II. is also a 3 pronged star of evaporated nature. The tracks are as follows:-

Track 1' is a thick track of alpha going out of the emulsion. Track 2' is due to a proton, which is ending in the emulsion. The residual range is about 110 microns. The mass was evaluated by grain density method. Track 3' is a small blob of the recoil nucleus.

The inter-connecting track is at minimum ionization and is only 120 micron long. The grains from the apex are showing an increase as we move from star I to star II. There was no other possibility of deducing any thing on such a short distance.

The peculiarity of this event is that they are inter-connected by a track at minimum ionization, which is not traceable in any direction beyond these stars. More-over, this is also practically certain that the track has started from star I and has caused the star II. The formation of the stars can^{not} be easily explained if we consider 2' to be a continuation of 4, then it has given a lot of energy (130 Mev. by proton) and the star of this type is unable to account for that much of energy.

Under the circumstances, the only explanation for this event can be given as follows:

Star I is initiated by neutron, which seems to have given out a knock-on proton (Track 4). This knock-on proton initiates stars II and again gives out a knock-on neutron (that is why the track is untraceable). Some energy dissipated in the nucleus has caused the two evaporation stars.

Track 5 cannot be assumed to be due to a π because the capture of π is not possible specially when π is moving at such ionization. Secondly, the production of π in such a small evaporation star, is also very rare. Thirdly, the neutron recoil by a π - as already assumed - is also not so easy.

The example represents a fine example of double star.

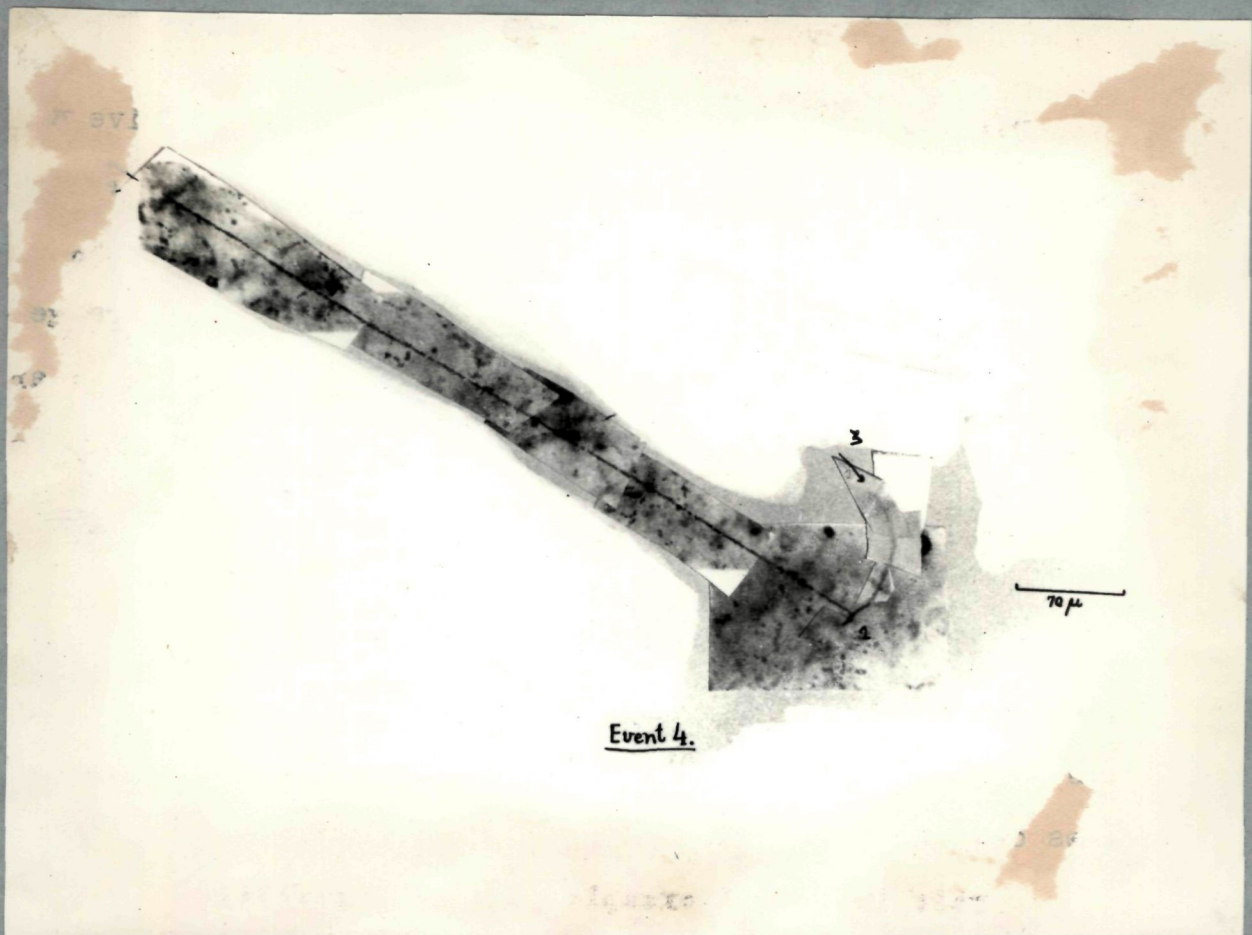


Fig. 16. Star caused by the capture of a π^- -meson.

E V E N T 4

The star of fig. 16 is a fine example of negative capture. The star has only 3 prongs.

Track 1 is a small heavy blob of recoil nucleus

Track 2 is ending in the emulsion. The total range of the particle is about ~~six~~ 652 microns. The total grains are 745. This shows the mass of the particle as proton, $(0.83 - 1.047)$ ($n' = 0.95$; $k^2 = 1.64$). This is a proton going out with a kinetic energy of 11 - 12 Mev.

Track 3 is very highly scattered track coming from outside. It exhibits a characteristic bend at the end of its range. The mass of the particle was calculated by grain density method and comes out close to π .

This is a good example of a star created by the capture of a π^- by a heavy nucleus. Such examples have been given by Menon et al. (1950).



Fig. 17. Star showing the disintegration of a heavy nucleus by a neutral particle . A meson shower has come out.

E V E N T 5

This event has been shown in fig. 17. It is a 21 pronged star, and again presents an example of the disintegration of a heavy nucleus, out of which a shower of high energy particles is coming out. The thick tracks are due to the evaporation of the nucleus.

Generally all the tracks are going out of the emulsion, except 13, 14 and 16. The length of each track is about 100-200 microns, therefore, the mass measurements were not possible on any track. Track 13 is a proton ending in the emulsion, while 14 and 16 are due to an alpha and a particle heavier than alpha respectively.

This again shows a nuclear disintegration caused by a neutron out of which a shower has come out.

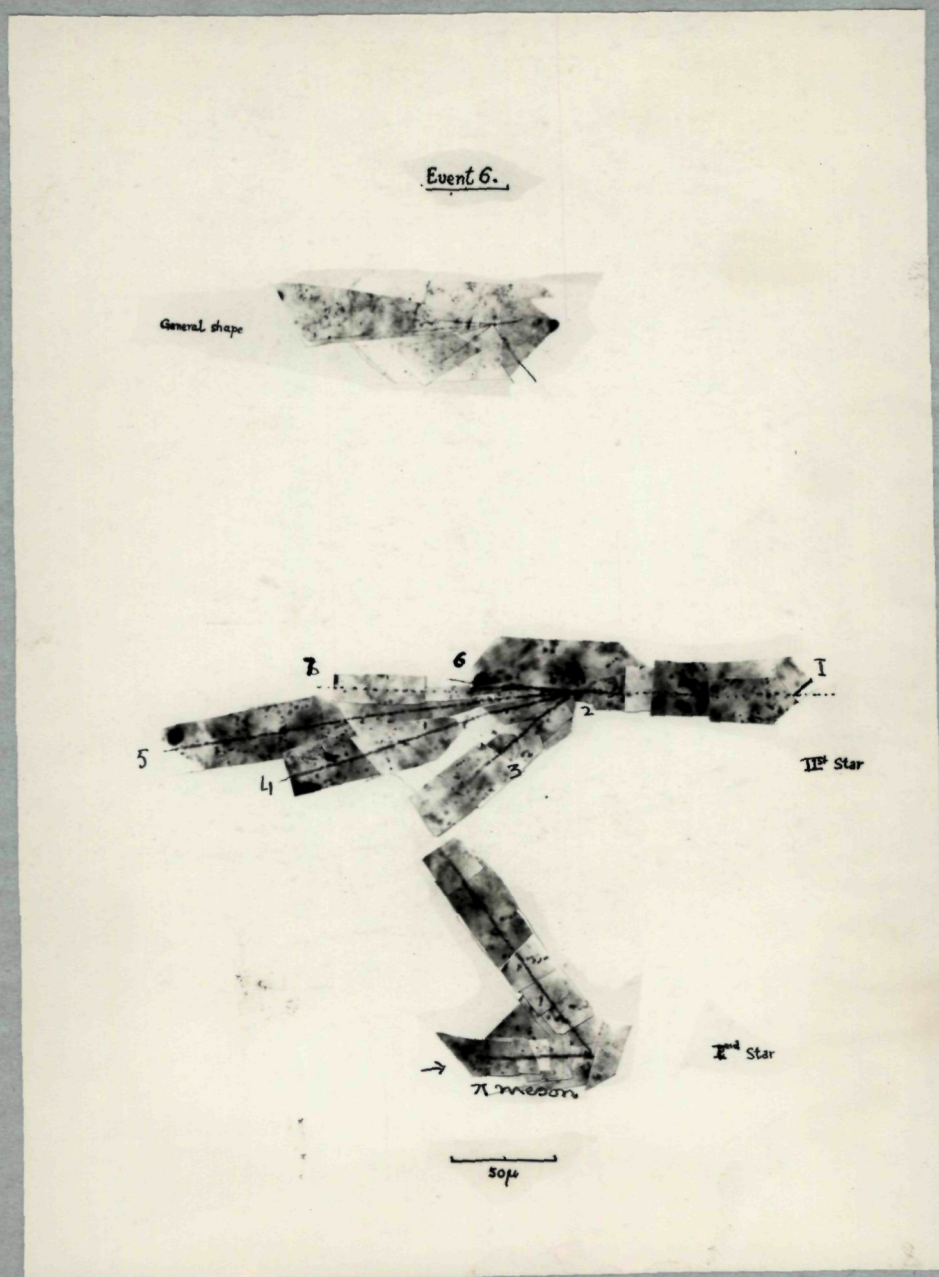


Fig. 18. Event observed in G5 200 micron thick plates exposed at 13,500 ft. This is superposition of two stars. Star I is a star initiated by a high energy proton while star II is due to the capture of π^- -meson.

E V E N T 6

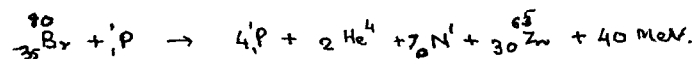
The event is shown in fig. 18 . This star has been created by a charged particle track 1. The total number of tracks are 9. A close inspection shows that there are actually two stars almost superimposed. The picture of the two stars is shown separately.

I. looks to be a π^- captured by a heavy nucleus at the end of its range. It has a blob at the apex. A proton seems to be coming out of it.

II. This is a 7 pronged star initiated by a proton. The identification of the tracks indicate that three tracks are due to ~~evaporated~~ evaporated protons viz. 3, 4 and 5. Track I is that of the initiating proton moving at the energy of 300 Mev. Track 7 is a proton at the energy of about 170 Mev. and seems to be the continuation of track 1. Track 6 is an alpha track (heavily ionizing) whose range is about 10 Mev. The energies of the particles forming the tracks 3, 4 and 5 are respectively 90, 50, and 20 Mev. Track 2 is a heavy recoil about 5 microns long.

The disintegration is that of a heavy nucleus (Ag, Br. and I) by a charged proton, which has given about 130 Mev. energy to the nucleus.

Most probable disintegration ~~scheme~~ scheme is as follows:-



This makes a fine example of super-position of events and the star created by a proton.

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C H A P T E R, VI

Rare - Events.

Introduction.

The use of counter controlled cloud chamber and the development of photographic emulsion technique not only gave new methods for the study of cosmic Ray Particles but has brought to light a number of new particles in the last few years. Upto 1947 the knowledge of fundamental particles was limited to Electrons, Positrons, Protons, Neutrons, and Mesons (μ). In the same year Powell gave his discovery of π Mesons (mass 276 me) and in 1948 Alkhanian et al² hinted at the existence of many types of charged mesons. They described these particles as veri-trons.

By the year 1953, the physicists had revealed the presence of about a dozen new unstable particles. These unstable particles are now classified in two main groups*. (1) Hypersons - (Y -particles) which include all the particles of mass intermediate between Proton and deuteron. (2) Heavy Mesons (K -mesons) - a general name for all the particles having mass between π meson and proton.

The above notations are subject to any change if the particles heavier than Deuteron are found. Some of these unstable particles are charged (charge being of both signs and equal to that of an electron) while some are neutral.

*The notations used throughout this chapter are those suggested by Amaldi et al (1954)³.

Hyperons.

This group includes mainly Λ^0 (Previously known as ν_1^0) and some Y-events reported (including Λ^+ which is a positive counterpart of Λ^0)

Λ^0 Particle.

The discovery of the particles was reported by Rochester and Butler in 1947⁴ while they were studying the penetrating showers by means of a cloud chamber. They observed some typical form type pictures. Due to the V shaped nature of tracks, these particles were named as V particles. (Λ^0 particles). Since the event did not have evaporation track, the example could not be explained as a scattering or nuclear interaction but was reasoned to be the spontaneous decay of some neutral particle, the probability of which depended on the distance travelled by the decaying particle and not by the matter traversed by it.

Hopper and Biswas (1950)⁵ found such example in photographic emulsion plates. Similar examples of particles were put forward by Armenteros et al (1951)^{6,7}; Astbury (1950)⁹; Leighton et al¹⁰; Thompson (1951)¹¹; Bridge and Annis (1951)¹³; Bridge et al (1953)¹⁴; Fretter (1953)¹⁵ and so on. First extensive study of these particles was made by Armenteros et al. They concluded on the statistical basis that the angle in Λ^0 is generally less than 90° and 180° while charged V generally showed an angle between 90° and 180° . The same group established the presence of two types of neutral particles according to the decay schemes: $\nu_1^0(\Lambda^0) \rightarrow p^+ + \pi^- (\text{or } \mu^-)$ and $\nu_2^0(\Theta^0) \rightarrow \pi^+ + \pi^- \text{ or } (\mu^+ + \mu^-)$

A two body decay scheme was accepted for both of these particles and hence the mass of (Λ^0) was found to be $(220 \pm 27) m_e$ if secondaries are π and that of Θ^0 to be (796 ± 27) if the secondaries are π and (705 ± 32) if secondaries are μ mesons.

The mass of the particle could be calculated (Armenteros et al)⁶ with the help of the energy equation in rest system viz.

$M = (p^2 + m_1^2)^{1/2} + (p^2 + m_2^2)^{1/2}$ where M, m_1, m_2 are masses of Λ^0 and if two

secondaries in energy units. This equation can be transformed to the laboratory frame of reference and we have $(M^2 + P^2)^{1/2} = (p_1^2 + m_1^2)^{1/2} + (p_2^2 + m_2^2)^{1/2}$

where P, p_1, p_2 are the momenta of primary and of two secondaries respectively. P can be expressed by the equation.

$$P^2 = p_1^2 + p_2^2 + 2p_1 p_2 \cos \phi \quad \text{--- (6.2)}$$

where ϕ is the angle between two forks. From above equations an explicit formulae for the mass (M) of the particle can be given as:

$$M^2 = m_1^2 + m_2^2 + 2p_1 p_2 \left[\left\{ 1 + \left(\frac{m_1}{p_1} \right)^2 \right\}^{1/2} \left\{ 1 + \left(\frac{m_2}{p_2} \right)^2 \right\}^{1/2} - \cos \phi \right] \quad \text{--- (6.3)}$$

where M, m_1, m_2 are in energy units. This gives the Q values as

$$Q = M - (m_1 + m_2) \quad \text{--- (6.4)}$$

Following this process, Rochester and Leighton found the values of mass and Q values of Λ^0 to be 2190 me and 30 mev respectively. While for θ^0 the mass was of the order of 950 me and Q values were about 250 mev.

Thompson et al (1953)¹⁶ put forward another decay scheme for neutral V . He found some examples of the type $V_3^0 \rightarrow (\tau^+ \nu \bar{K}) + \pi^- + 60 \text{ mev}$. The data, however, is of little statistical weight.

The presence of Λ^0 particle is now almost certain.

τ -Meson.

This was investigated by Brown et al (1949)¹⁷ in the emulsion.

After allowing all the possibilities they arrived at the conclusion that the particle recorded was a new particle which had undergone a spontaneous decay and has ejected 3 π which are co-planer.

Ceccarelli (1952)¹⁸ showed definitely that no combination of π or μ was possible. The mass of the primary was calculated to be 978 me with Q values about 86.5 mev.

However, recently Dixit (1955)¹⁹ has reported one example of τ which has decayed into two π -meson and a μ -mesons but further examples are needed for ~~establishing~~ establishing the presence of such a decay scheme.

K(Kappa) Meson and K meson.

O' Calligh (1951)²⁰ in the course of studies of decay electron from the μ meson with emulsions reported the existence of a new type of particles which decayed into μ meson whose range was 1078 microns in contrast to 600 microns. The mass measurements showed the incident particle to be of mass (1125 \pm 200) me. Since then about 20 examples of this type of decay have been reported by Menon, O' Calligh, Crussard,²¹ Levisetti, and so on. In all the cases the secondary particle has been confirmed to be a μ meson. Only in few cases there is a doubt that ejected particle may be π or μ

Thus this group was phenomenologically divided into two groups. (1) K-(Kappa) which decays in μ and (2) \bar{K} -meson which decays in a π meson. The ejected π meson always had a unique kinetic energy of 120 mev and mom. of 250 mev/c.

Since the μ mesons from kappa mesons have very different energies, it was concluded that the mode of decay of the particle must include at least 3 particles - one charged and two neutral as: $K^{\pm} \rightarrow \mu^{\pm} + \nu^0 + \bar{\nu}^0$ The differential momentum spectra of this decay scheme was also consistent with a 3 body decay scheme. The nature of these neutral particles is still undecided. In the case of \bar{K} -meson since the π meson always comes out with a unique energy the simplest form of the decay scheme may be given as $\bar{K}^{\pm} \rightarrow \pi^{\pm} + \nu^0$

Mass of K-meson has been found to be 1100 me while that of \bar{K} meson to be (1460 \pm 320) me. For K the estimated mass of neutral particle is about 300 me.

Friendlander, Keefe, Menon and Van Rossum (1954)²³ as reported an example of β decay of K-meson. Here a particle of mass (1050 \pm 100) me had decayed in an electron with the values of $\beta\beta$

equal to (88.56) mev/c. The grain density and scattering showed that the particle was definitely an electron. Some further evidence of such β decay has also been reported by the same group.

Charged V

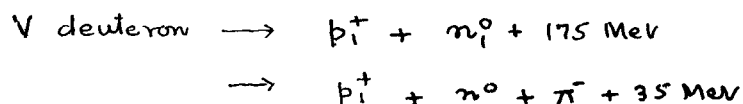
This particle was also reported by Rochester and Butler in 1947⁴ along with Λ^0 . The secondary was identified as a pion. Armentros⁶⁻⁸ reported many examples of this particle but it was found that the charged V particles were rarer than V. The ratio has been reported to be 1:6. Charged V has been found to decay both in flight and at rest. For slow charged V data has been presented by Leighton (1952)²⁵ Astbury (1952-53)^{9,24}. Leighton has given the mass of the primary as (1200 \pm 300) me and mass of secondary as (250 \pm 50) me, while Astbury has reported the mass of the primary as (1100 \pm 500) me. The momentum of the secondary lies between (175-225) mev/c. Armentros have given some examples of fast charged V and he has reported the mass of the primary < 1600 me.

The transverse momentum distribution of charged V was not consistent with two body decay schemes but seem to follow a three body or more complicated decay schemes.

Charged Hyperons & double decay scheme.

This is also called V cascade. Armenteros gave the example of a double decay ^{where} whose a heavy particle decayed according to scheme $\Lambda^+ \rightarrow \Lambda^0 + \pi^+$ meson. The examples of this type of decay are also quite few as yet.

Frier, Ney and Sard¹⁶ indicated the possibility of V neutrons and indicated an approximate life time of 10^{-10} seconds for such particles; the possible decay scheme are either



Peters²⁷ has presented an example of Σ deuteron decaying in a deuteron and a π^- . The Q value of this decay scheme are of the order of 90 mev. Much more data is required for drawing definite conclusions. Friedlander (1954) has presented examples of such charged hyperons which decay according to the following scheme

$$\gamma^\pm \rightarrow L^\pm + \pi^0 + Q$$

In some cases the secondary is a fast proton. The mass of primary has been found to be (2800 ± 600) me by scattering method and (2870 ± 600) me by gap-density method. The value of β (v/c) was 0.26. The secondary was a π or μ meson. The value of $\beta\beta$ was calculated to be (87 ± 3) mev/c for π and (66 ± 2) mev/c for μ . Q values are of the order of 100 mev.

Apart from it some examples of stopped particles (e particles) were also presented by Bridge and Annis.¹³ Danyaz. Danyaz (1952, 1953)^{18,19} put forward some examples of Σ^0 particles which decayed in $\pi^+\pi^-$ but now this particle has been included in θ event. Some of these unstable particles interact strongly with matter. The examples of production of these heavy mesons have been found in jets. Some examples of production have also been found in high energy nuclear disintegrations at mountains. The data on these particles has been summarised by Rochester and Butler (1953)³⁰ and C.F. Powell (1954).³¹

Rare events at mountain altitudes observed by the author.

Some evidences of the decay of these particles have been obtained in this laboratory in the emulsion plates by the author. The plates are the same type as already described in chapter V viz. 200 micron thick Ilford G emulsion plates which were exposed at the altitude 13,500 feet and 9000 feet with and without absorber. The absorber used was 6 cm. of lead. Other details of the method

of exposure and the ways of processing etc. have already been discussed in preceeding chapter. These events have been found in the total scanned area of 225 sq. cm.

All these events are two pronged and the following possibilities can be attached (1) that the events may be due to large angle scattering suffered by a particle, moving through the plate. (2) That they may be ordinary nuclear disintegrations. (3) That they may be due to the spontaneous decay of some particle.

The first possibility required firstly a small blob at the apex - if the scattering has occurred due to a silver nucleus or the scattering nucleus has also caused some ionization - secondly a continuity in the ionization even if the blob is absent. The second requisite is much more important. But in all the events the grain densities of the tracks comprising the events were much different from each other. Moreover no blob was visible at the apex. Hence it was believed that the events under consideration were not due to large angle scattering.

The second probability also required either an evaporation or a recoil track. But the absence of any such track indicated that all these events were definitely the examples of spontaneous decay of some particles. Various methods (already described in chapter IV) have been used for the determination of the quantities viz. momentum, energy, mass etc. The shrinkage factor were determined by direct measurements with microscope at about 25 points in different region of the plate. The value is given in each case whenever necessary. For applying equation (4.2) for mass determination by grain density the values of constants K' and n' was found by finding some known standard tracks in the plates. Generally a $\pi \rightarrow \mu$ decay or proton track ending in the emulsion or a π^- giving rise to a capture star were chosen for the purpose. All the three

types of tracks have their characteristic features and it is very unlikely that any mistake is made in their identification. The grains and residual ranges are measured for each track. The value of exponent n' was found by plotting the value of (dn) and (dr) on a long-log paper and finding the slope of straight line thus obtained. Finding the value of n' we can calculate the value of K' . An average was found for all the tracks and these values were used for any further calculations in the same plate.

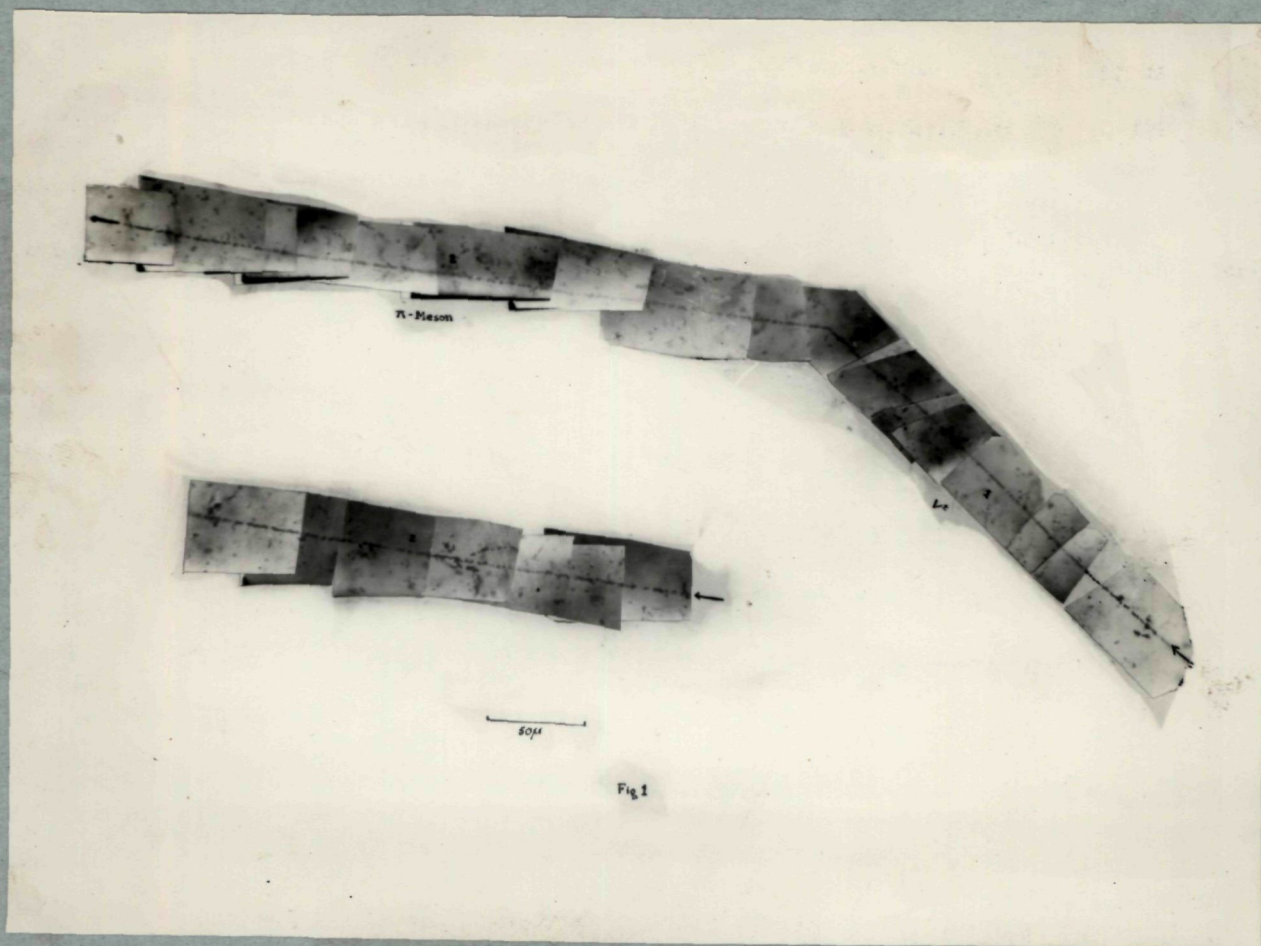


Fig. 19. Two pronged event observed in 200 microns, G5 emulsion plates, exposed at 13,500 ft. The primary coming from outside has been identified to have a mass about $(1140 \pm 200) m_e$ which decays into an L-meson. The primary is most probably a charged V.

Event 1

This event is shown in Fig. 19 which was found in the plates exposed at 13,500 feet above sea-level without any absorber. Here a particle coming from outside has undergone a spontaneous decay. The value of shrinkage factor of the plate was found to be 2.5.

The value of constant n' found by the method described above is 0.925 while that of K' is 1.669 or the value of $\log K$ (0.2012 - .2224) which gives an average as 0.2118.

Primary

The incident particle is coming from the outside and has an approximate grain density of (49 ± 4) grains per 50 micron. This gives the value of grain density (as 2.4 ± 0.2) g_{min} (where g_{min} is the grain density of a relativistic particle in the plate). This value of grain density gives the rate of energy loss (Fowler and Perkins, 1951), $dE/dr = (2.6 \pm 0.1)$ Kev/micron. With the help of eqn. (4.2') of chapter IV, we get $2.6 \pm .1 = 0.587 \beta^{-1.46} Z^2$ taking the value of Z as 1, we have $2.6 \pm 0.1 = 0.587 \beta^{-1.46}$ which gives the value of $\beta = (0.35 \pm 0.02)$. The track is not long enough to make accurate measurements of scattering but it is indicated that mass of the particle lies between π meson and proton. An approximate value of the mass comes out to be (1140 ± 200) me.

Secondary

The secondary is quite long and leaves the emulsion after about 1.5 mm. It has approximate grain density of (29 ± 2) grains per 50 microns in the beginning which changes to about 32 ± 2 grains per 50 microns at the end. This corresponds to a value of grain density as $(1.5 \pm 0.1) g_{min}$.

No measurements of grain density and range were possible for mass evaluation.

The value of scattering was found by the methods described by Goldschmidt and Clermont (1948) (Chapter IV) to be (0.787 ± 0.029) degrees per 100 microns, which gives the value of $p\beta = (33.15 \pm 1.25)$ mev. This indicated that the particle is either a π or μ . The value of β can be found in the same way as described before. This gives the value of momentum as 85.80 ± 2.49 mev/c if the particle is π meson and 65.28 ± 1.80 mev/c if it is μ meson. Corresponding energies for π meson and μ mesons are (23.49 ± 1.27) mev and (17.87 ± 0.97) mev respectively.

The above data indicated that a K-meson has undergone a decay into an L-meson. The conditions indicate that the secondary is more likely to be a π meson rather than being a μ meson. The most probable decay scheme can be given as

$$V^{\pm} \rightarrow \pi^{\pm} + \text{neutral particle.}$$

No estimate of the nature of charge was possible. However, the statistics of information do not discard the possibility of this event being a Kappa meson, undergoing a decay into a μ meson.

The above information of a rare event is valuable with the idea that it has been produced in air, because the plates were placed without absorber; while generally other workers have found the examples of such particles at mountain altitudes with the plates exposed under some absorber.

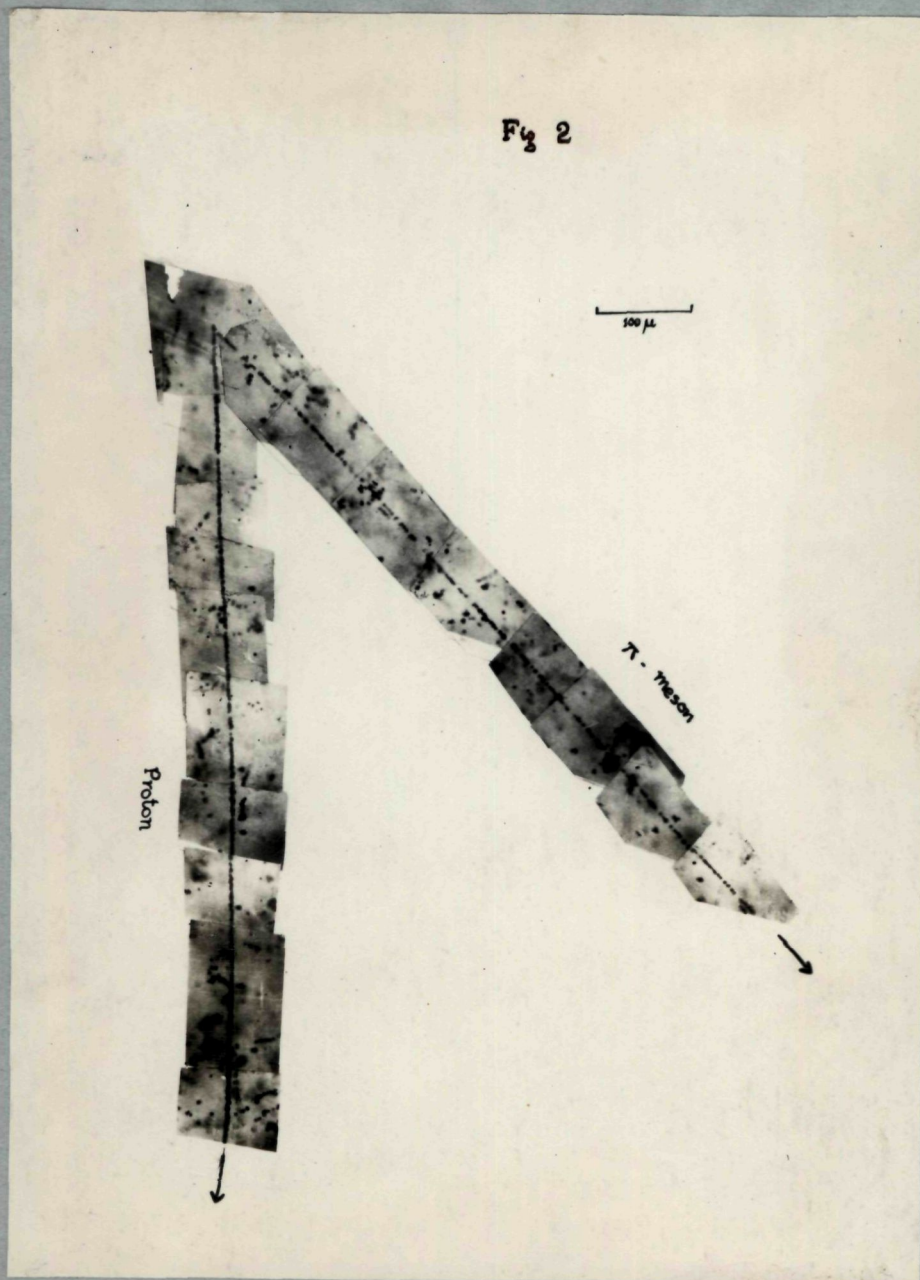


Fig. 20. Two tracks originating from a common apex, observed in 200 micron thick, G5 emulsion plates, exposed at 9,000 ft under lead. One track has been identified due to proton while the other due to a π meson. The event shows the decay of a neutral V (Λ^0) of mass about $(2115.6 \pm 130) m_e$.

Event 2

This event is shown in Fig. 20. The event has been found in the plate exposed at 9000 ft under 6 cm. of lead. Here two particles are emerging from a common apex. The measurements in each track are given below.

Track 1

This track is coming to rest in the emulsion, hence the mass identification was almost certain. The grain density and range method was, used for the identification of its mass.

The residual range of the particle was 436 microns taking the shrinkage factor into consideration. Total number of grains were found to be (544 ± 16) . This gives the value of mass (equation 4.2) to be 1.047 mp where mp is the mass of a proton.

The total number of gaps in this range were also found and the comparison with standard curves indicated the particle to be close to a proton. The scattering measurements were not possible because the track was too short for such measurements. The value of energy was seen from the range energy curves Fig. 8 and was checked by evaluating the energy loss (kev/micron) from the curves of Fowler and Perkins (1951) and using equation (4.2'). The value of momentum of the particle comes to be (133.4 ± 4.1) mev/c.

Track 2

This track is going out of the emulsion after a distance of more than 1 mm. It had a grain density of 47 ± 1 grain per 50 microns which remains more or less constant throughout

the range. This goes to indicate that the particle has moved in with more or less uniform velocity in the whole reign. The variation in grains from the apex also confirmed that the particle had started from the apex and gone out of emulsion. This was also confirmed by seeing the total number of gaps in the segment of 200 microns. The number of gaps varied from the apex as 21, 18, 13 indicating a decrease in the number of gaps as track proceeded from the apex confirming thereby that the particle has moved out from the apex.

The coulumb scattering (deg./100 microns) was found by method of Goldschmidt - clermont and the value was found to be (0.42 ± 0.02) deg./100 microns. All this information confirmed that the particle was a π meson. The momentum of this π meson was calculated to be (67.5 ± 2.3) mev/c.

The angle between these two tracks was $39^\circ 45'$.

Since both the tracks were moving out from the apex, it was concluded that the tracks under consideration were the decay products of some neutral particle. The neutral particle has decayed in a proton and π meson. The momentum of the neutral particle was calculated by using eq. (6.2)

$$\begin{aligned} P^2 &= p_1^2 + p_2^2 + 2 p_1 p_2 \cos \phi \\ &= (133.4)^2 + (67.5)^2 + 2(133.4)(67.5) \cos 39^\circ 45' \\ P &= 190.3 \text{ Mev/c} \end{aligned}$$

After knowing the momentum we can find the mass of the particle using equation 6.1 given by Armenteros et al (1951)

$$(M^2 + p^2)^{1/2} = (m_1^2 + p_1^2)^{1/2} + (m_2^2 + p_2^2)^{1/2}$$

The notation used has already been explained. This gives the mass of the particle to be (2115.6 ± 130) me. The Q value of this process comes out to be of the order of 24 mev.

All this information indicates that the neutral particle which has suffered spontaneous decay is a Λ^0 . The decay scheme is as follows:-

$$\Lambda^0 \rightarrow \underline{p^+} + \pi^- + 24 \text{ MeV}$$

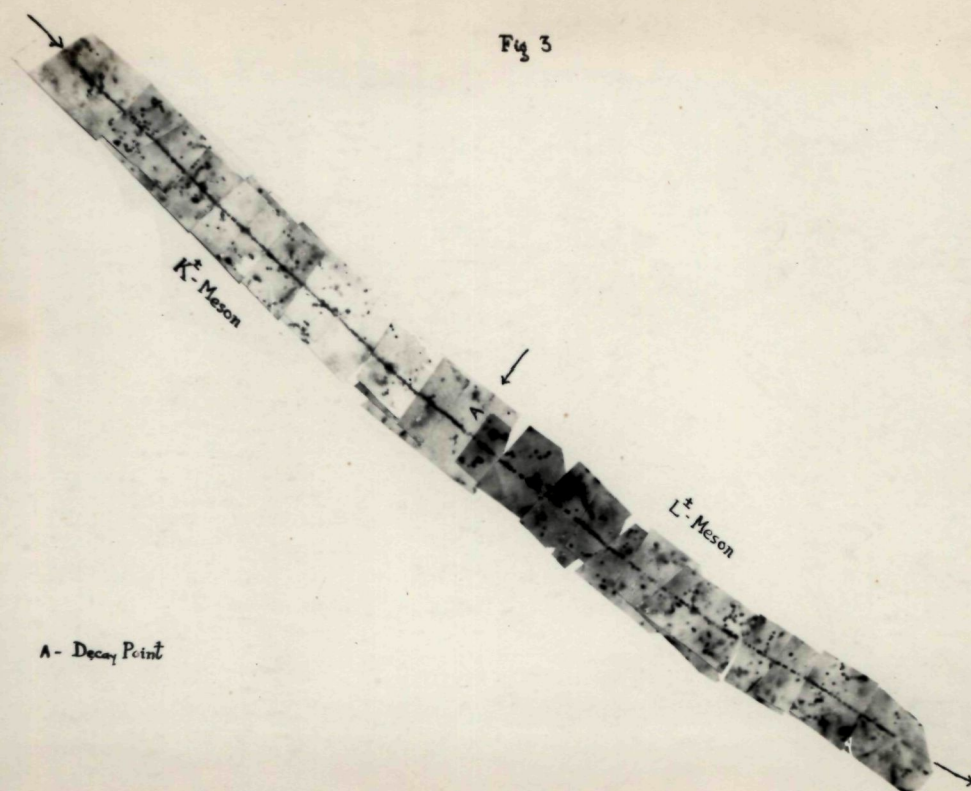


Fig. 21. An event observed in 200 micron thick G5 emulsion plate exposed at without any absorber. The incoming K meson has come to rest in the emulsion and has decayed into an L- meson.

E V E N T 3

Event 3 is shown in Fig. 21 . This event has also been found in plates exposed at 13,500 ft. without absorber. A particle has entered the plate and has practically come to rest. Then it has decayed into another particle which finally leaves the emulsion.

The primary was ending in the emulsion, hence its mass was calculated by the method of residual range - grain density. The range of the particle was about 500 microns (taking account of the shrinkage factor). The value of $(\log K')$ and (n') in the equation (4.2) were found to be 0.3746 and 0.86 respectively. Total number of grains counted were 464 ± 20 . This gives the mass of the particle to be 1287 ± 85 me. The available range was insufficient for making any reliable measurements. However, a verification of mass was done with the help of gap length - range measurements. The gaps exceeding a given length were measured and the mean gap length was calculated with the help of equation (4.9). The mean gap length was found to be 0.3 microns which is equal to 3.42 scale divisions. When this was plotted on the standard curves the point indicated the particle to have a mass intermediate between Proton and a π meson and much nearer to proton. All the above measurements confirmed that the particle under consideration was a K-meson.

The secondary leaves the emulsion after about 1.4 mm. It has a grain density of about (41 ± 2) grains per 50 microns. It shows a scattering of (0.54 ± 0.12) deg. per 100 microns. This when compared with standard curves showed that the particle is an L-meson which will have a momentum of (68.97 ± 16.0) mev/c if it is a π meson and (53.23 ± 13.00) mev/c if it is a μ meson.

Thus this event presents a slow K-meson decaying into an L-meson and some neutral particle or particles; viz.

$$K^{\pm} \rightarrow L^{\pm} + \eta^0$$

The particle has practically come to rest in the emulsion and may be taken as S-particle as reported by Bridge and Annis (1951).

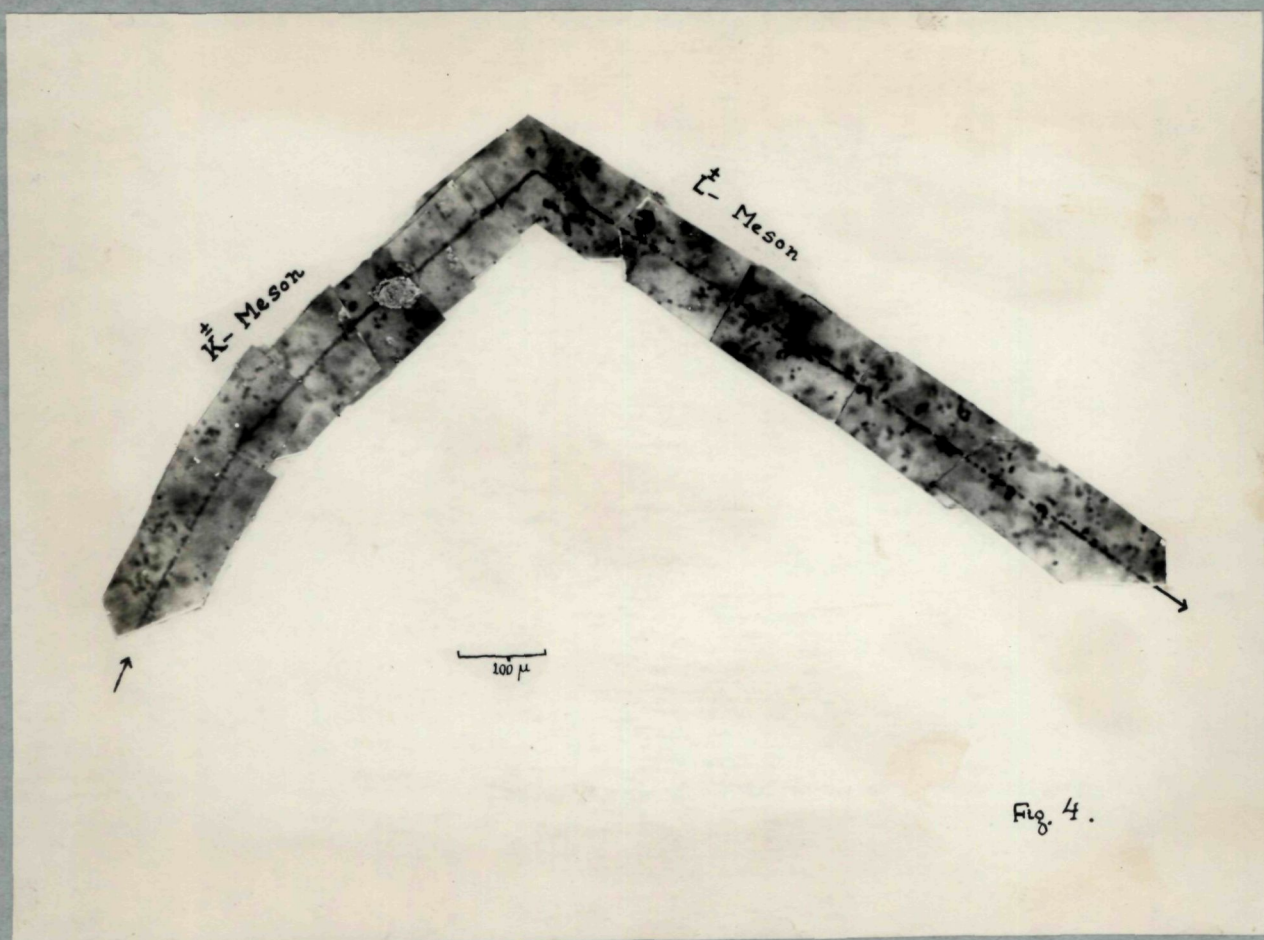


Fig. 4.

Fig. 22. The K meson coming from outside has decayed into an L-meson. The event has been observed in G5, 200 micron thick emulsion plate. The mass of K meson is about (1161 ± 110) .

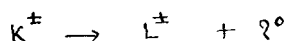
E V E N T 4

The event shown in figure 22 was also found in a plate exposed at 13,500 ft. under no absorber. This event comprises of two particles one of which is coming from outside and has quite appreciable ionization while the other originates at the point where first ends and has smaller ionization than the previous one. After a full verification it was concluded that the first track is due to primary particle which has decayed in another high energy particle.

The primary is again of short length in the emulsion. The mass was calculated with grain density - residual range method and was verified with other methods. The range of the primary was about 405 microns (with about 399 grains in all). The mass of the particle was estimated to be (1161 ± 110) m. The mean gap length measurements also confirmed that the particle was a K-meson with mass intermediate between Proton and a π meson.

The secondary having a grain density of 50.5 grains per 50 microns shows a scattering of 1.24 degrees per 100 microns. It leaves the emulsion after about 1 mm. Comparing this with standard curves, it was concluded that the particle is an L-meson. Its momentum values are (52.27 ± 14.2) mev/c, if it is a π meson and (41.10 ± 11.4) Mev/c if it is a μ -meson.

From this information it was concluded that this event also represents the decay of a charged K-meson into an L-meson. But here the product (L-meson) is a slow one as indicated by its grain density. The general scheme of the decay could again be written as in the previous example, viz.



The close analysis indicates that the above particle was most probably a decay of a Kappa-meson decaying into a slow μ meson, but any-how the probability of the decay of slow charged V cannot be ruled out.

Fig 5

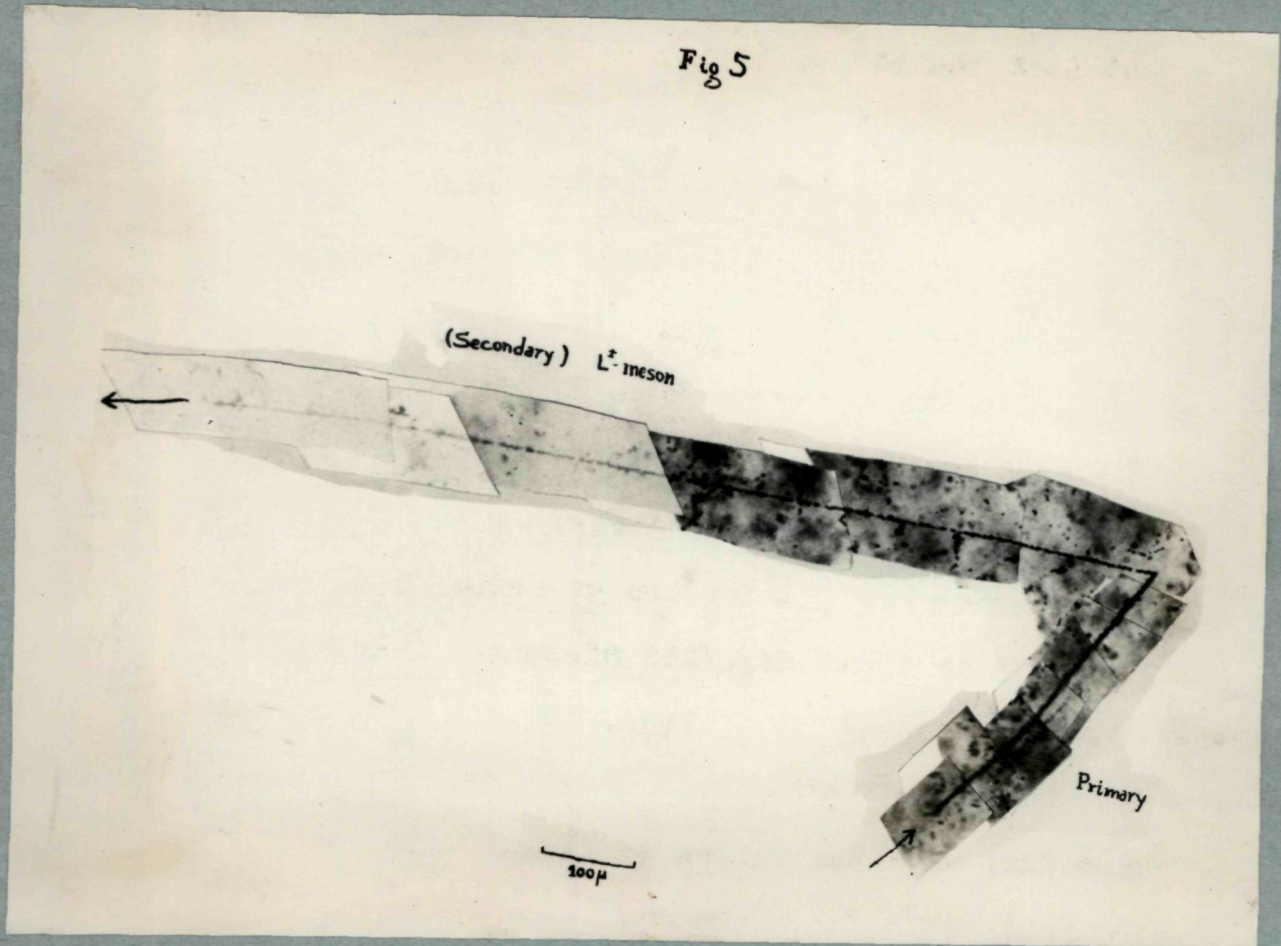


Fig. 23. A charged K meson observed in 200 micron thick G5 emulsion plate exposed at 13,500 ft. The secondary goes out with an energy of (23 ± 2) mev if a π -meson and (17.3 ± 1.6) mev if a μ -meson.

E V E N T 5

This is also a two pronged event found in the plates exposed at 13,500 ft. without absorber. This also seems to be a decay of some charged particle, which has entered the plate from the outside.

The secondary is about 1.3 mm. in length in the emulsion, after which it goes out. It has an average grain density of (54 ± 4) grains per 50 microns. The coulumb scattering measurements were done with two different cell lengths, viz. 50 microns and 25 microns. The values were found to be 0.715 deg./100 microns; and 0.748 deg./100 microns respectively. From these values the mean scattering after the elimination of noise (Equation 4.5) was calculated to be 0.692 deg./100 microns. This clearly indicated that the particle was an L-meson. It has an energy of (23 ± 2) mev if it is a π -meson and (17.3 ± 1.6) Mev if a μ -meson. This gives corresponding momentum values as (94.1 ± 7.0) mev/c for π -meson and (71.9 ± 5.0) mev/c for μ -meson.

The particle seems to be more probably a π -meson rather than a μ -meson.

The primary, which has entered the emulsion from the outside, has again a very short length - only of a few hundred microns. (~ 200 microns). It has appreciable ionization and has about 64 grains per 50 microns. Nothing more could be ascertained in this case.

The above information indicated that some particle has decayed into an L-meson (most probably a π -meson) which goes out with an energy appreciably higher than presented in an example of $\pi \rightarrow \mu$ decay. The primary also seemed to have a mass near to that of a Proton. Thus

we could conclude that the primary which is again a charged K-meson has decayed into a slow L-meson. The decay scheme is similar to that given in last two examples.

Under the above information it was hard to establish a more certain identity of the particle and the decay scheme.

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